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AEROSPACE ENGINEERING

"The prestige magazine of the Aerospace Industry"

VOLUME 19 / NUMBER 10 **October 1960**

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COMPUTENCE

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Letters

Wanted! More Articles on Aircraft Engineering

■ As an IAS member and steady reader of the AERONAUTICAL ENGINEERING REVIEW—more recently AEROSPACE ENGINEERING, I wish to make the following comments with respect to the nature of its contents.

I fully understand the need to extensively publicize and propagate all aspects of the space sciences, a pressing matter not only within the overall technological framework, but also for our national prestige and its international implications. However, in my opinion, it is a fundamental error with irreparable and detrimental consequences to grossly neglect or ignore the aeronautical science as applied to aircraft.

The aircraft is our most important medium of transportation. Although it seems to have reached its highest refinements, there are still many questions as yet unanswered, such as:

(1) What progress has been made in higher economy and low fares?

(2) What is the best speed and economy compromise for $M > 1$ airliners?

(3) Boundary-layer control, which presents entirely new aspects and possibilities.

(4) VTOL and STOL progress, including that of autogyros and helicopters.

(5) Flutter analysis and safety (Lockheed Electra accidents).

(6) Landing gear design problems (Boeing 707 accidents).

(7) Lateral directional stability at low speeds (CV 880 accidents).

(8) Fail-safe structures and load analysis.

It is rather amazing that one must resort to foreign publications to obtain information on these subjects. On the other hand, AEROSPACE ENGINEERING *is the only U.S. journal which has the adequate technical level* to act as reporter of the aircraft developments steadily being accomplished in this country.

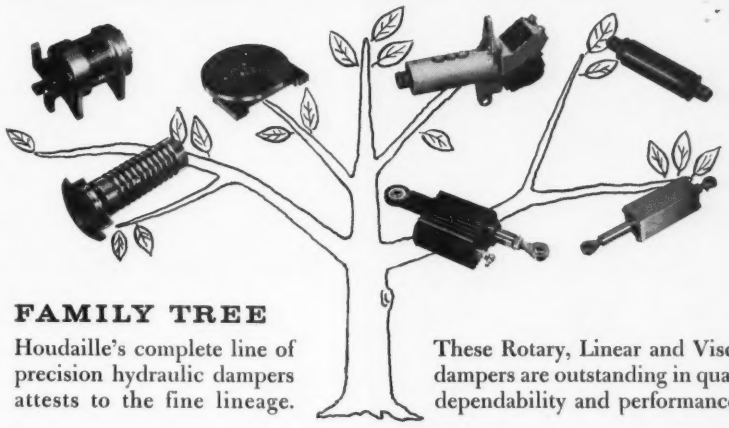
I would like to suggest that, along with the space sciences, more aeronautical articles be published in AEROSPACE ENGINEERING. Please invite your readers in the aircraft industry and research institutes to publish their work, their findings and suggestions. There would then be an efficient source of information and exchange of experience among aircraft engineers. (They are still here!)

Our country not only has to become "Space-First" but must remain "Air-First."

Karl L. Sanders, MIAS
Prelim. Design Eng., Manned Vehicle Proj.
Ryan Aeronautical Co., San Diego, Calif.

(EDITOR'S NOTE: *The job of* AEROSPACE ENGINEERING *is to provide technical data of value to all IAS members, the goal being publication of articles on "air" and "space" in equal number. Articles on aircraft engineering, therefore, remain of importance, and we echo Mr. Sanders' suggestion to workers in this field to report their findings and submit their work for publication.*

Biography of a Damper



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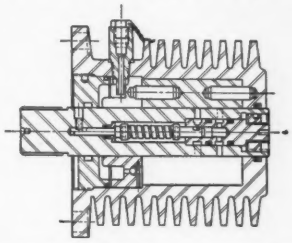

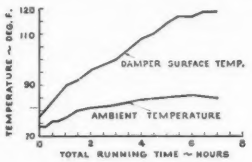

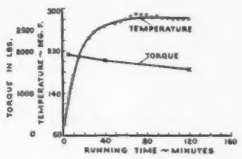

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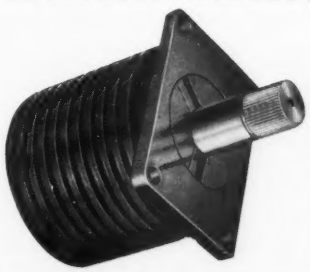

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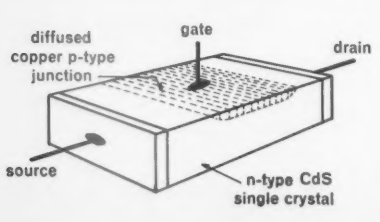
Still in the early experimental stage, this phototransistor is a tangible result of the General Motors Research Laboratories' program on semiconductors — particularly the group II-VI compound, cadmium sulfide. Behind its development lies the steady accumulation of (1) know-how in crystal growing, doping, and contact preparation and (2) information about CdS's intriguing solid state properties (red or green luminescence, high photoconductivity, short relaxation times, etc.).

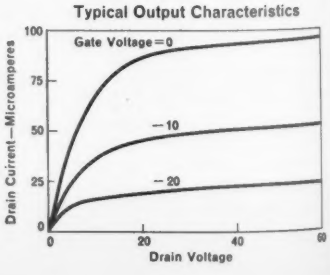
For the researcher, this three-terminal device is adding a new dimension to the fundamental understanding of semiconductors. For instance: GM Research scientists have uncovered the important role of photo-generated holes in modulating the conductance of this intrinsic semiconductor and have determined the hole drift mobility through a new theoretical analysis.

These semiconductor investigations illustrate the dual aim of GM Research: contributions to the science, advances in the technology of important new subject areas. Such research is the initial step in General Motors' continuing quest for "more and better things for more people."

General Motors Research Laboratories

Warren, Michigan





EDITORIAL

IAS International

The second International Congress of the Aeronautical Sciences has come and gone. Some 500 delegates from all over the world met in Zurich, Switzerland, during the week of September 12–17 to listen to and discuss some 60 papers originating in 24 countries on subjects relating to the aerospace sciences. In attendance were representatives from the U.S.S.R., Poland, Yugoslavia, and other Iron Curtain countries. Red China was conspicuous by its absence.

As most IAS members are aware, these Congresses are organized under the International Council of the Aeronautical Sciences. ICAS was formed by a group of international scientists during the annual meeting of the Institute in New York in 1957. Dr. Theodore von Kármán took an active part in its founding, and has since served as Honorary President. Maurice Roy, Director of ONERA in France, has served as Chairman of the ICAS Executive Committee and with his committee has been responsible for the success of the technical programs for both Congresses—the first in Madrid in September 1958 and the second in Zurich this year.

The work of ICAS is financed by a fund administered by the IAS which resulted from the sale of the Daniel and Florence Guggenheim estate at Sands Point (L.I.) to the U.S. Navy in 1951. The staff of the Institute acts as the Secretariat for ICAS, with ex-officio representation on ICAS operating committees. This arrangement has proved to be a very happy one. The collaboration among all elements has been close and complete—as the success of the two Congresses has amply demonstrated.

Long-range planning is essential for such a widespread operation. It was agreed by the Council in Madrid two years ago that the third Congress (1962) would be held in Stockholm, Sweden. En route to Zurich in late August, IAS Secretary Bob Dexter and IAS Controller Joe Maitan spent several days in Stockholm conferring with Council Member Bo Lundberg of the Swedish Aeronautical Research Institute and examining the physical facilities available there for use two years hence.

While in Europe in connection with ICAS affairs, a number of meetings were held in connection with our other international commitments. Most important were talks held in London with the Royal Aeronautical Society with reference to planning and programs for the Eighth Anglo-American Aeronautical Conference scheduled in England for the early fall of 1961. At a joint meeting of the Councils of the two Societies held in New York during the Seventh Annual Meeting in 1959, it was agreed that the Anglo-American Conferences should continue, and that their scope should be extended to bring the Canadian Aeronautical Institute more closely into the picture. Secretary Dexter met with Dr. Ballantyne, Secretary of the RAeS, and with David Boyd, President of the CAI, in London and in Zurich, and the group arrived at a mutually satisfactory *modus operandi* for the content and conduct of the 1961 Conference.

Most immediate of our international programs is the annual joint meeting with the CAI scheduled for Montreal, October 17–18, 1960. As has been usual for many years, both Societies have shared in the development of the program for which our Canadian colleagues will be host.

In the past few years our scientific and technical interests have been extended upward "from Zero to Infinity." At the same time our professional collaboration has spread horizontally around the world.—SPJ

Surface Effects on Materials in Near Space

Francis J. Clauss

Missiles and Space Division, Lockheed Aircraft Corporation

SPACE FLIGHT is now an established reality, and advanced systems are being designed to perform complicated missions, such as reconnaissance and sentry-type duty, to detect the launching of ballistic missiles from any point on earth. Manned space flight and space exploration are other examples of advanced spacecraft. These systems require more complexity, better reliability, and longer operation than the early satellites launched into orbit. And one factor that becomes very important in meeting these requirements is the behavior of materials in space. Several problems that are associated with the behavior of the surfaces of materials in space are discussed in this paper.

Dr. Clauss is a Research Scientist with the Missiles and Space Division, Lockheed Aircraft Corp. He is presently conducting research on the lubrication of gears and bearings for operation in ultrahigh vacuum; on the stability of temperature-control surfaces under prolonged exposure to ultraviolet radiation, vacuum, and orbital temperature conditions; and on other aspects of the behavior of materials under space conditions. He was Technical Chairman of the symposium on "Surface Effects on Spacecraft Materials," cosponsored by Lockheed and the ARDC in May, 1959, and was Editor of the transactions of that symposium. Prior to joining Lockheed in 1959, Dr. Clauss was at the Lewis Research Center of the NASA where he was engaged in research on high-temperature metals and alloys for turbojet engines and aircraft nuclear propulsion systems. Dr. Clauss holds advanced degrees in both chemical and metallurgical engineering (Ph.D., University of Michigan) and has authored over 20 scientific papers, principally in the field of high-temperature metallurgy.

Temperature-Control Surfaces

The choice of materials for the outer surfaces of spacecraft is determined primarily by the need to maintain temperatures within limits that are set by the requirements of the payload. To date, these payloads have been electronic equipment and power supplies and a few animals. In the future, they will be more complicated electrical, mechanical, and optical systems, as well as humans.

Background

Since space is essentially a vacuum, aerodynamic heating is negligible, and essentially all heat transfer, both to and from spacecraft, occurs by means of radiation. The temperature-control systems therefore used are passive systems in which the outer surfaces are tailored for the job of receiving and emitting radiant energy in balanced amounts. It is much the same idea that one might use in selecting clothes for the tropics—dark clothes absorb sunlight and would make one warm, whereas light-colored clothes reflect the sunlight, and are therefore cooler.

One of the important characteristics of radiation that complicates matters somewhat from this simple idea is the wavelength of the radiation. Radiation from a hot body, such as the sun, has shorter wavelengths than that from a cold body. Correspondingly, an important characteristic of a temperature-control surface is its relative ability to absorb the short-wavelength or high-temperature radiation it receives and emit, in turn, long-wavelength radiation.

Fig. 1 shows the behavior of some ideal surfaces and helps explain this. Emissivity, which is plotted as the ordinate, is the ratio of the energy emitted from a given surface to that emitted from a black body at the same temperature. It varies with wavelength, but always has a value between zero and one. The emissivity equals the absorptivity at the same wavelength, and the reflectivity equals one minus the emissivity. In other words, a surface with high emissivity in Fig. 1 is a good emitter at a given wavelength, a good absorber, and a poor reflector (and vice versa).

Short-wavelength radiation (to the left side in Fig. 1) is present in both the solar radiation that strikes spacecraft directly and in the solar radiation that is reflected or scattered by the earth's atmosphere back out into space and against the spacecraft. This is the major type of radiation received by spacecraft, and more than 99 per cent of it has wavelengths shorter than 4 microns, or 40,000 Angstroms, and includes the spectrum of visible light. Long-wavelength radiation, in the infrared portion of the spectrum, is typical of that given off by cooler bodies, such as spacecraft. There is also some long-wavelength radiation received by spacecraft that must be considered in the heat balance; this is the earth and atmospheric emission, which is the solar ra-

Material behavior is an important factor in the long-time operational reliability of satellite systems and spacecraft. During the early years, when the possibility of space flight was first being considered, some scientists recognized that the environment of outer space might cause materials to behave differently and introduce new problems different from their use on earth. However, the urgent problems that required attention first were those of propulsion, structures, guidance, and telemetry, and it was not until the ability to place satellites into orbit had been demonstrated that the problems of long-time operational reliability in space became real.

diation that is absorbed by the earth and its atmosphere and then reradiated at a lower temperature. Another source of heat that must be considered is the heat dissipated internally by the operation of electrical systems.

Surface temperatures are governed by the relative heights of the curves in the two-wavelength regions. This is termed the alpha-over-epsilon ratio, and it expresses the relative ability to absorb the high-temperature radiation from the sun, and then reradiate it at lower temperatures. Solar absorbers have higher values for alpha than for epsilon and, therefore, a high alpha-over-epsilon ratio; in other words, they absorb energy from the sun more efficiently than they emit it at lower temperatures, and they would run hot.

Certain polished metals, such as stainless steel and aluminum, behave as solar absorbers; they generally have alpha-over-epsilon values of about 3, or more.* Solar reflectors are just the opposite to solar absorbers; they have low alpha-over-epsilon ratios and would maintain lower temperatures. White oxides, such as flame-sprayed aluminum oxide coatings, are solar reflectors, having alpha-over-epsilon ratios generally less than 0.3. Flat absorbers have uniformly high values of both alpha and epsilon and alpha-over-epsilon ratios near unity; flat reflectors have uniformly low values of both alpha and epsilon and also have alpha-over-epsilon ratios near unity.

Real materials approximate the ideal behavior shown in Fig. 1, so that spacecraft surfaces can be made up by combining several real surfaces into a patchwork that has the required alpha-over-epsilon ratio to maintain a desired temperature. It is not necessary to describe the behavior of specific materials here. Many laboratories are making emissivity and related measurements, and there are many tables and graphs available that present this sort of information (see, for example, references 1 and 2).

One should not suppose that temperature control is as simple in practice as it might sound in principle. The geometry of the spacecraft and its orbit in space must also be considered, and the problem may be complicated by other requirements such as high visibility, as with the Vanguard satellites. Rather sophisticated mathematical procedures have been developed for calculating the required values of emissivity and absorptivity for a specific mission, and such calculations must be made by all groups launching satellites.[3–5]

As an example of the range of values involved, the equilibrium temperatures for a spherical satellite in a certain 200-mile orbit range from 95° to −60°C. as the alpha-over-epsilon ratio is changed from four to one-quarter; or, in other words, there is a temperature range of 155°C. for changing from a highly polished metal surface to a surface coated with something like aluminum oxide.[5]

Experience to Date

The following paragraphs summarize the experience to date with passive temperature-control surfaces.

For the Explorer I satellite,[4] the internal temperatures

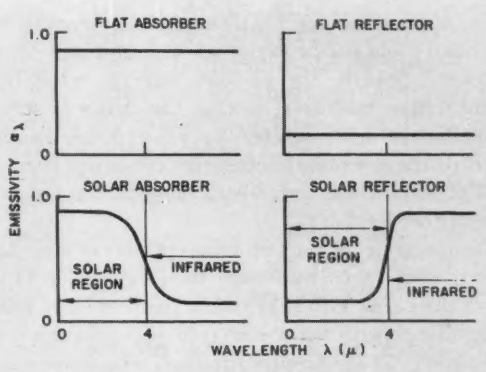


Fig. 1. Radiation characteristics of ideal surfaces.

* Typical values of alpha and epsilon for polished 2S aluminum are 0.30 and 0.05, giving an alpha-over-epsilon ratio of 6. Although polished aluminum is a good reflector of visible light, it is a very poor emitter of infrared radiation and for purposes of temperature-control surfaces is classed as a solar absorber. That polished metal surfaces would be hot on a spacecraft can be easily verified by placing one's hand on such a surface after it has been held in the sun for a short time.

in the nose cone and the attached cylindrical section had to be kept between −5° and +50°C. for the batteries and electronic equipment to operate properly. The two sections were made of stainless steel—type 430 for the nose cone, and type 410 for the cylinder—which had been sandblasted in order to "pre-erode" its surface so that any subsequent erosion in space would not alter its optical properties. Thirty per cent of the nose cone and 25 per cent of the cylindrical section were coated with Rokide A, an aluminum oxide coating developed by the Norton Company. This gave surfaces with average alpha-over-epsilon values of 1.61 and 1.37. Temperatures transmitted in orbit showed internal fluctuations inside the nose cone from about 5° to 40°C., and inside the cylinder from 0 to 35°C., both of which were within the prescribed limits. Shell temperatures ranged from −25° to +75°C.—a considerably wider variation than that internally.

For the Navy Vanguard satellites,[5, 6] high visibility was required, as well as temperature control, in order to permit visual tracking. The temperature range from −10° to +60°C. was set by the mercury batteries and transistors. The Vanguard II was a 20-in. sphere of gold-plated magnesium alloy which was given a multilayer coating of evaporated chromium, silicon monoxide, aluminum, and a final layer of silicon monoxide. This multilayer coating was developed by the Army Lab. at Fort Belvoir. The aluminum coating had to be opaque enough to give maximum reflectance in the visible, and the final layer of SiO, which is responsible for the temperature control, had to be transparent in the visible. Thickness of the final SiO layer was about 6,500 Angstroms. The alpha-over-epsilon ratio for this coating is 1.3, and this resulted in a temperature in the package of the satellite that stabilized at 34°C. after approximately 5 days in orbit.

For the lunar probes, the Pioneers III and IV,[4] the requirements differed somewhat from those for the satellites. First, since the trajectory is more critical, it was not possible to regulate the launch time in accordance with the requirements for temperature control, and possible delays in firing required that the coatings be changed day by day if postponements became necessary. Second, radiation from the earth could be neglected during the important portions of the flight. Third, the amount of heat generated internally was larger and could not be neglected, as it had been for the Explorer. Fourth, the payload was protected by a shroud during launching, so that the choice of surface materials was not restricted by aerodynamic heating. And fifth, the allowable temperature range was from 20° to 50°C., which was only about one-half the range allowed for the Explorer.

The nose cones of the two Pioneers were of fiberglass, covered with a gold wash, and then striped for 44 per cent of their area with either white paint or black paint, in accordance with the special orbital requirements for each probe. The adjacent cylindrical wrapping around the battery pack was a gold-plated aluminum foil shield, with 40 per cent striped black for Pioneer III, and 43 per cent striped white for Pioneer IV. For both Pioneers, the annular base of the battery pack was gold plated and unpainted, and the remaining portion of the base was sprayed with aluminum paint. Payload temperatures rose steadily after launching as the lunar probes moved out from the shadow of the earth, and reached steady values of about 37°C. for Pioneer III, and 42°C. for Pioneer IV, both of which were within the prescribed range.

Future Requirements and Areas for Development

Although passive temperature-control surfaces have been successful in the past on satellites and lunar probes, future requirements will impose additional demands. For example,

(1) Permissible temperature ranges will be narrowed, in accordance with the requirements of more precise and complex instrumentation. There are, in fact, certain specialized devices that require control to within a fraction of a degree.

(2) Internal generation of heat will increase as the power requirements go from their present low levels to the much higher levels required by advanced systems. This means that the internal heat must be dissipated to space more efficiently from external surfaces of high emissivity.

(3) Sizeable portions of the external surfaces will be occupied by windows for viewing from the ultraviolet to low radio frequencies. Other special requirements, such as good radar reflection, may be added.

(4) There will be large changes in the solar energy input as the vehicles move nearer to or farther from the sun, and this will require corresponding adjustments in the alpha-over-epsilon ratio. Entry into foreign planetary atmosphere might upset the operation of a temperature-control system during its return to earth. One thing needed here is more precise information about the space environment, particularly for interplanetary flight.

(5) The continuous operation for many months and years will expose the outer surfaces to the cumulative deterioration due to erosion and other factors of the space environment.

Because of these problems, *active* controls will be needed. These may be mechanical devices, such as shutters or rotating fan blades that expose different surfaces with different alpha-over-epsilon ratios as the conditions demand. Electric heaters and coolers may also be needed in some areas. Active control systems do not, of course, eliminate temperature-control surfaces. On the contrary, such surfaces reduce the overall weight and power required, and are therefore an important part of any system.

Probably the two most important needs here are (1) developing reproducible coatings and standardized procedures for measuring their optical properties, and (2) establishing their durability in space.

Effect of Space Environment on Surface Stability

Optical properties of surfaces depend on very thin

films, on the order of the wavelength of light. Such films must be stable against sublimation into high vacuum, or by erosion by dust particles, micrometeorites, or sputtering, and changes that might occur due to radiation, such as extreme ultraviolet radiation and Van Allen radiation. Long before these environmental conditions can affect sufficient material to weaken a vehicle structurally, enough damage can be done to surfaces to upset the conditions for controlling temperature, supplying power, or looking out of windows or through telescopes.

(1) Sublimation Into High Vacuum

Evaporation from surfaces, or, more correctly, sublimation in the case of solids, is much faster into a vacuum than when the surfaces are covered by a blanket of air or vapor molecules. Knowing the vapor pressure and temperature of a material, one can calculate its rate of sublimation, on the assumption that an atom or molecule that leaves the surface does not come back (certainly a safe assumption for surfaces evaporating into space). Such calculations indicate that the lightweight structural metals titanium, beryllium, and aluminum would not sublime at significant rates at their expected use temperatures. Pure magnesium could be troublesome if it was used as a bare metal surface and was heated about 65°C. hotter than the upper shell temperature measured on the Explorer (see above). As a practical matter, magnesium alloys are used rather than the pure metal, and the alloys are coated with stable finishes, so that the sublimation of magnesium from temperature-control surfaces in space is not a real problem.

Some metals are sufficiently volatile to cause problems in other applications than temperature-control surfaces. Zinc and cadmium, for example, both have even higher vapor pressures than magnesium. Their application to plate parts used in satellite systems could cause troubles like short-circuiting because of their evaporating and then plating out on exposed electrical circuits. In fact, one can think of a satellite as a large vacuum plating chamber, such that any volatile material put into it will evaporate from warm surfaces and plate out on cooler surfaces.

Sublimation from metals can be retarded by inorganic surface coatings, such as oxides, which often have lower vapor pressures than the metals from which they are formed.

On the other hand, organic materials usually have much higher vapor pressures than metals.[7] Plastics behave differently, according to their processing, and plasticizers that are added to them are still more volatile. Absorbed moisture also contributes to the vapor pressure of many plastics. Using an organic material as a matrix for temperature-control paints is not possible in their present stage of development because of their high rates of sublimation, as well as other problems. Therefore, there is an interest in developing inorganic compounds for paint vehicles to carry and bind pigments of temperature-control paints.

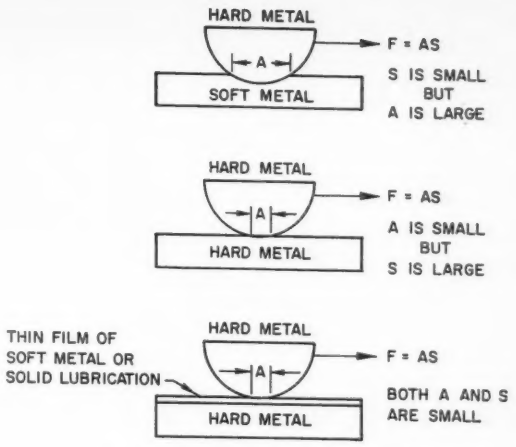


Fig. 2. Lubrication by thin films of solids.

(2) Degradation by Short-Wavelength Electromagnetic Radiation

One of the other problems with organics is their degradation by short-wavelength electromagnetic radiation, such as extreme ultraviolet and soft X-rays. Ultraviolet radiation in space is considerably more intense than on earth, because the atmosphere absorbs most of it and essentially nothing below 3,000 Angstroms wavelength reaches the earth's surface. Common examples of ultraviolet degradation on earth are the darkening of skin during sun-tanning, and the stiffening and embrittlement of some early grades of plastic garden hose when left in the sunlight.

Without going into the mechanisms involved, the practical end effects of radiation on plastics can be either an increase or a decrease in strength, a decrease in solubility, embrittlement, loss of adhesion, discoloration and enhanced electrical conductivity, depending, of course, on the particular material and conditions. Heating irradiated polymers can also cause foaming. Ultraviolet radiation in vacuum can promote excessive molecular cross-linking of film-forming resins, such as might be used as the matrix for coatings for temperature-control surfaces, and this would probably cause the films to shrink and lose their adherence to the substrate.[8]

Degradation of plastics and other organic materials by heat, vacuum, and various types of radiation is not, of course, limited to temperature-control surfaces, but should be considered wherever such materials are used in spacecraft in applications such as electrical insulation for wires, adhesives, seals and gaskets.

(3) Erosion by Solid Particles

Estimates of the severity of damage to optical surfaces by erosion vary from "not important" to "destructive," depending upon the assumptions made in estimating it.

Calculations based on solar corona and zodiacal light indicate that the number of impacts by micrometeor-

(*Continued on page 56*)

"The central point of this note is not that the kinematic constraints must be introduced by means of Lagrangian multipliers, but rather that they may not be ignored."

On Optimum Rocket Trajectories and the Calculus of Variations

R. M. Rosenberg, *University of California, Berkeley*

THE WEALTH OF RECENT ARTICLES utilizing the calculus of variations in the solution of problems concerning optimum rocket trajectories is now focusing the attention of the engineer on this beautiful discipline. However, like many another mistress, although beautiful, she is not always faithful. She will serve with fidelity those who have a light hand and a fine touch, but she tolerates no bullying.

The history of errors committed in the application of the calculus of variations dates back nearly to its conception. For instance, in solving the problem of the brachistochrone between a point on a given curve and a fixed point, Lagrange[1] in 1760 overlooked the dependence of the integrand on the initial point and gave an incorrect result. This error was noted and corrected by Borda in 1767; with the characteristic honesty and frankness which marks the true scientist, Lagrange acknowledged and corrected[2] his own error. As in the eighteenth century, errors are still committed in the use of the calculus of variations. Let us hope that we have not forgotten in the twentieth century how to acknowledge and correct them.

Recently, some articles[3–5] dealing with optimum flight paths have appeared which dealt with finding functions $y_i(x)$ with respect to which an integral was to become stationary under a certain set of auxiliary conditions. It was conjectured[3, 4, 6, 7] and denied[8–11] that certain auxiliary conditions need not, and indeed must not,[6] be adjoined to the variational problem. The special conditions regarded as superfluous are kinematic constraints, which were said to be physically intrinsic to the problem, natural and self-evident in character, and automatically satisfied by all extremals.

Inasmuch as this difference of opinion has a unique and unequivocal resolution, and since ignoring the correct answer leads to erroneous results (principally as well as numerically), it appears worthwhile to find that correct answer. In particular, we shall show that failure to adjoin the kinematic constraints to the variational problem leads to incorrect results. Therefore, the views set forth in references 8, 9, 10, and 11 are correct and those in references 3, 4, 6, and 7 are in error.

Suppose we wish to find the functions $y_1(x)$, $y_2(x)$ which, together with their first derivatives, are continuous on the interval $[x_1, x_2]$, which satisfy the boundary conditions

$$\left.\begin{aligned} y_i(x_1) &= y_i^{(1)} \\ y_i(x_2) &= y_i^{(2)} \end{aligned}\right\} \quad (i = 1, 2) \tag{1}$$

which satisfy the equation

$$\varphi(x, y_1, y_2, y_1', y_2') = 0 \tag{2}$$

and which give a stationary value to the integral

$$J = \int_{x_1}^{x_2} f(x, y_1, y_2, y_1', y_2')\, dx \tag{3}$$

Here f and φ are known functions of their arguments which we assume, for convenience, as analytic although this requirement could be relaxed.

By introducing a parameter α, one can replace the Eq. (2) by the two equations

$$\psi_i(x, y_1, y_2, y_1', y_2', \alpha) = 0, \quad (i = 1, 2) \tag{4}$$

From the general theory of the Lagrange multipliers, a necessary condition for the solution of the problem

is that the y_i satisfy

$$(\partial F/\partial y_i) - (d/dx)(\partial F/\partial y_i') = 0, \quad (i = 1, 2) \quad (5)$$

where we may define F alternately as

$$F = f + \lambda\varphi \quad (6)$$

or

$$F = f + \lambda_1\psi_1 + \lambda_2\psi_2 \quad (7)$$

Using Eq. (7), the Euler equations are

$$\left\{\frac{\partial f}{\partial y_i} - \frac{d}{dx}\frac{\partial f}{\partial y_i'}\right\} + \left\{\frac{\partial}{\partial y_i}(\lambda_1\psi_1) - \frac{d}{dx}\frac{\partial}{\partial y_i'}(\lambda_1\psi_1)\right\} + \left\{\frac{\partial}{\partial y_i}(\lambda_2\psi_2) - \frac{d}{dx}\frac{\partial}{\partial y_i'}(\lambda_2\psi_2)\right\} = 0, \quad (i = 1, 2) \quad (8)$$

Let us now assume that the condition $\psi_2 = 0$ is a natural, intrinsic condition which need not, and indeed must not, be adjoined. Then the Euler equations would be

$$\left\{\frac{\partial f}{\partial y_i} - \frac{d}{dx}\frac{\partial f}{\partial y_i'}\right\} + \left\{\frac{\partial}{\partial y_i}(\lambda_1\psi_1) - \frac{d}{dx}\frac{\partial}{\partial y_i'}(\lambda_1\psi_1)\right\} = 0, \quad (i = 1, 2) \quad (9)$$

If both formulations (8) and (9) are correct, they must lead to the same result; thus, the difference between Eqs. (8) and (9) must vanish, or

$$(\partial/\partial y_i)(\lambda_2\psi_2) - (d/dx)(\partial/\partial y_i')(\lambda_2\psi_2) = 0, \quad (i = 1, 2) \quad (10)$$

For simplicity we will now assume that the equation $\varphi = 0$ was split into the two Eqs. (4) in such a way that one of them, say $\psi_2 = 0$ is free of the derivatives y_1' and y_2'. This can not invalidate our results because $\psi_2 = 0$ may now be regarded as a differential equation in which the coefficients of the derivatives are zero. If our supposition leads to contradictions in that case, it can not become consistent in the more general case. Under the above assumption on ψ_2, Eq. (10) becomes

$$\lambda_2(\partial\psi_2/\partial y_i) = 0, \quad (i = 1, 2) \quad (11)$$

and we must have either $\lambda_2 \equiv 0$, or $\partial\psi_2/\partial y_i = 0$.

If $\lambda_2 \equiv 0$, Eqs. (8) and (9) become identical and the latter (for instance) will yield solutions

$$y_i = y_i(x, \alpha), \quad (i = 1, 2) \quad (12)$$

The parameter α will appear in the solutions since it is contained in $\psi_1 = 0$.

However, had we formulated the problem by means of Eq. (6), we should have had to solve the equation

$$(\partial/\partial y_i)(f + \lambda\varphi) - (d/dx)(\partial/\partial y_i')(f + \lambda\varphi) = 0, \quad (i = 1, 2) \quad (13)$$

and the solutions to this problem do not contain α since f and φ are free from it. Therefore, the two methods do not lead to the same result and $\lambda_2 \not\equiv 0$.

Therefore, we must assume

$$(\partial\psi_2/\partial y_i) = 0, \quad (i = 1, 2) \quad (14)$$

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These are two *finite* equations of the form

$$g(x, y_1, y_2) = 0, \quad h(x, y_1, y_2) = 0$$

In principle, they may be solved simultaneously to yield unique solutions

$$y_1 = y_1(x), \quad y_2 = y_2(x)$$

having unique boundary values

$$y_1(x_1) = y_{11}, \quad y_1(x_2) = y_{12}, \quad y_2(x_1) = y_{21}, \quad y_2(x_2) = y_{22}$$

Therefore, the functions $y_i(x)$ cannot, in general, satisfy the boundary values of Eqs. (1) or, *in general, no solutions exist which satisfy both Eqs. (14) and the constrained variational problem in hand.* But, under the the general assumptions on the y_i, f, and φ, it is evident that nonexistence of solutions cannot be demonstrated. Consequently, *the supposition that the constraint* $\psi_2 = 0$ *need not be adjoined is false.*

We would now like to demonstrate by a well-known example that failure to adjoin kinematic constraints leads to absurd results and is, therefore, not recommended.

Let $x(t)$ denote a displacement x which is a function of the time t, and let $v(t)$ be the velocity. Under specified initial conditions $x(0) = x_0$, $v(0) = v_0$, we wish to find the stationary value of

$$J = \int_0^\tau f(t, x, v)dt \quad (15)$$

where

$$f(t, x, v) = T(v, x) - V(x) \quad (16)$$

and, by definition,

$$v - \dot{x} = 0 \quad (17)$$

If $T(v, x)$ is the kinetic energy (positive, definite) and $V(x)$ is the potential energy, the example is the well-known Hamilton integral.

The constraint of Eq. (17) is kinematic. It simply states that the time derivative of the displacement is the velocity. It is precisely of the type which was not adjoined in references 3, 4, and 5 because it is intrinsic, self-evident, and automatically satisfied by all com-

(*Continued on page 64*)

An approach to axial flow compressor design which permits the designer to use two-dimensional analysis for high-performance engines.

Controlled Radial Energy Gradient in Axial Flow Compressors

Lt. Col. Edward M. Rex, USAF, MIAS, *United States Air Force Academy*

EVEN IN this era of rocket propulsion, the turbojet engine has a definite future. This future includes two important applications. First, the recovery of the booster stage for ballistic missiles and space vehicles is desirable for economic reasons. A feasible solution to this problem is the use of an air-breathing type of engine to accomplish this recovery. Second, the field of supersonic transportation shows great promise for rapid expansion. Here the use of the turbojet is obvious. Both of these applications demand the continuation of development in the field of high-performance turbojet engines. This high-performance requirement has forced engineers to consider the three-dimensional approach to the problem of axial flow compressor design. This report presents a method whereby even these high-performance engines can be successfully designed with only the popular two-dimensional analysis rather than the complex three-dimensional approach.

Background

During the evolution of the turbojet engine, much emphasis has been placed on improving the performance parameters of specific weight, specific fuel consumption, and thrust per square foot of frontal area. As a consequence of increasing this latter parameter, designers have been forced to "cram" more air through a given frontal area. In order to accommodate this high mass flow, axial compressors with low hub-tip ratios were necessary.

This requirement made designers relinquish the free vortex type of blading. Free vortex assumes two-

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Symbols

C = absolute velocity
h = enthalpy
p = pressure
r = radius
T = temperature
u = wheel speed, internal energy
v = specific volume
W = relative velocity
ρ = density
ω = rotational speed

Subscripts

u = tangential direction
x = axial direction
0 = stagnation conditions
1 = entering conditions
2 = leaving conditions

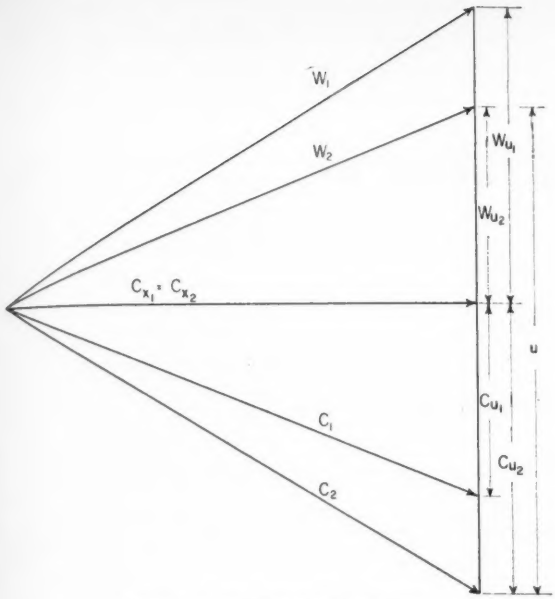


Fig. 1. Symmetrical velocity diagram.

dimensional flow, constant circulation, and axial velocity invariant with radius. Having constant axial velocity made the two-dimensional assumption quite good since, theoretically, there is no radial flow if there is no displacement of the streamlines. In addition, this condition permitted designers to use the following simple relationship* for radial equilibrium:

$$dp/dr = \rho(C_u^2/r)$$

This two-dimensional approach to compressor design had the added advantage of convenience. When a designer imposed the conditions of free vortex flow—namely, equal work at all radii, axial velocity invariant with radius, and simple radial equilibrium—the analytical equations would lead to the condition rC_u = constant.

As a result, the free vortex design became less "messy" as far as the analytical development was concerned.

At first, departure from the free vortex principle was necessary due to the high relative Mach numbers created by the higher mass flows. To alleviate this limitation, designers yielded the condition of constant axial velocity and imposed another stipulation that would reduce the relative Mach number restriction. For instance, designing for 50 per cent constant reaction would help solve the high Mach number problem.

This solution proved short lived, however, as far as the two-dimensional design criterion is concerned. Once the condition of constant axial velocity (with radius) was removed, the assumption of no radial flow was no longer valid. If the axial velocity is a function of radius, it usually is a different function before and after the stator or rotor. This causes considerable radial flow because, in order to satisfy continuity, the middle streamline must be deflected to a different radius.

As the hub-tip ratios decreased, the two-dimensional analysis became completely inadequate. Under these conditions, the high-performance engines must be designed using the three-dimensional phenomenon which has been avoided for years. Among other considerations in this complex flow pattern, the simple relationship for radial equilibrium is no longer applicable.

The purpose of this note is to introduce an idea in which it appears feasible to apply the two-dimensional analysis to these high-performance engines. The idea is not new. It concerns controlling the radial energy gradient through the use of a special first stage. This paper, however, proposes to control it in a unique way.

Development

If we start with the hypothesis that a designer wishes to maintain an accurate two-dimensional analysis for an axial flow compressor but still wishes to abandon the free vortex flow concept, there are two definite conclusions—(1) he must design for constant axial velocity, and (2) the resulting radial energy gradient cannot be zero (as is the case for free vortex

(*Continued on page 64*)

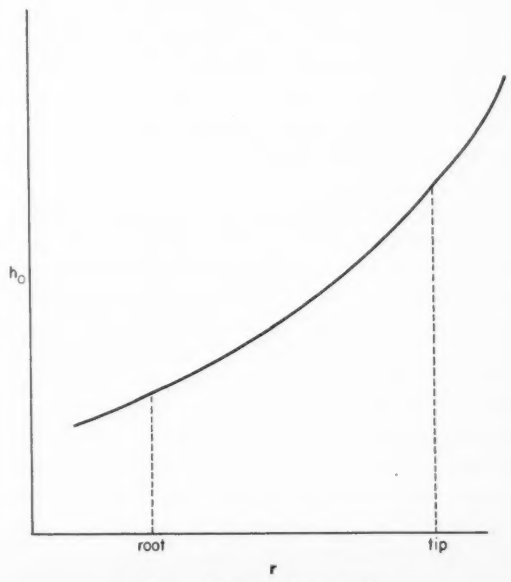


Fig. 2. Total enthalpy vs. radius.

* This equation represents the pressure gradient normal to a streamline. For the condition of constant axial velocity, the normal direction is along the radius, and, therefore, the radius of curvature is the radius itself. This simple relationship is valid only when the assumption of no radial flow is reasonably accurate. For the more complex three-dimensional flow, in which there exist radial flow and radial accelerations, the simplified relationship is of little value.

Problems in Attitude Stabilization of Large Guided Missiles

Can the control problem be alleviated by appropriate configuration selection?

Ernst D. Geissler, MIAS; George C. Marshall Space Flight Center, NASA

ATTITUDE CONTROL of guided missiles is generally necessary, at least, during the propelled phase of their flight in order to enforce a flight path leading toward the prescribed target. The guidance system provides information about necessary maneuvering and will define a required attitude of the missile. Particularly for ballistic missiles, the guidance system will try to keep the missile reasonably close to a standard trajectory, although, in case of nonstandard conditions of certain flight parameters, some guidance systems tend to select deliberate deviations from standard flight path. However, the amount of maneuvering involved in executing a standard trajectory under normal conditions (deflection from vertical start), as well as correcting for certain nonstandard conditions, is usually small (in terms of required torques and g loads) compared to requirements upon the control system arising temporarily from disturbances by wind forces and other factors upsetting the torque balance (as misalignments of engine, or even failures of individual engines in missiles with cluster-engines).

Configurations which are aerodynamically unstable—i.e., have the center of pressure forward of the center of gravity—are obviously most sensitive to atmospheric disturbances. A missile of conventional shape will be unstable unless stabilizing fins are attached, because the center of pressure of the fuselage alone is close to the shoulder, whereas the center of gravity is far behind (close to the geometric center). The provision of stabilizing fins becomes less and less attractive with increasing size of a missile because of large weight penalties involved, and because the increasing span width tends to interfere at launch with various auxiliary launch-equipment structures.

Artificial stabilization through the control system rather than provision of a stable airframe appears indicated for larger missiles. This requires availability of control torques, which may be produced by air vanes, jet vanes, jetevators, swivelling of the engines, or other means (plug nozzles). Control by gimbaled engines has been successfully employed in several larger missiles (notably two, the IRBM and ICBM), and is being planned for the Saturn vehicle, the large-multiengined space-vehicle booster under development at Huntsville. It has the advantage of availability of control torques regardless of dynamic pressure and little loss of propulsive power for small deflections. Limitation of maximum required control deflections to reasonably small values is imporant in view of increasing complexity of flexible feeding lines to engine, gimbal bearings, adequate closure of missile base for protection from backflow of hot gases and radiation from jet clearances, and possibly most important, structural requirement for engine mounts and airframe. Also, limitation of angles of attack to be encountered by the missile during flight is of interest in view of structural loads on the fuselage.

Dr. Geissler began his scientific career (1940) under Dr. Wernher von Braun at Peenemuende, where he worked on control and flight theory of guided missiles. Brought to the United States by the Government in 1945, he worked on guided missile aerodynamics and flight mechanics at Fort Bliss, Tex. Later, he served as Director, Aeroballistics Lab., Redstone Arsenal, Ala., and in the same capacity with the Army Ballistic Missile Agency, activated in 1956. At the present time, he is Director of the Aeroballistics Div., George C. Marshall Space Flight Center at Huntsville. In April, 1959, Dr. Geissler was awarded the Department of the Army Decoration for Exceptional Civilian Service. He is a member of the IAS, ARS, and the NASA Research Advisory Committee for Missile and Spacecraft Aerodynamics. Dr. Geissler received his Ph.D. from the University of Darmstadt in 1951.

$$\frac{c_1}{c_2} = -\frac{\pi q c_\alpha' D^2}{4F}$$

WITH q DYNAMIC PRESSURE

c_α' SLOPE OF NORMAL FORCE COEFFICIENT

D DIAMETER OF FUSELAGE

F THRUST OF SWIVEL-ENGINE

s DISTANCE OF c.g. AHEAD OF BASE

h DISTANCE OF CENTER OF PRESSURE AHEAD OF BASE

A CROSS SECTIONAL AREA

Θ MOMENT OF INERTIA

$$c_1 = \frac{(s-h) q A c_\alpha'}{\Theta}$$

$$c_2 = \frac{SF}{\Theta} \text{ (ASSUMING SWIVEL POINT AT BASE OF MISSILE)}$$

Fig. 1. Ratio of aerodynamic torque per unit angle of attack over control torque per unit deflection angle for a swivel-engine controlled missile.

It will be shown, in the next section, that control requirements (in terms of control torque and angle of attack) for a given configuration are strongly dependent upon the mode of operation of the control system, and can be reduced considerably by use of an attitude reference more sophisticated than the space-fixed reference as used in the earliest guided missiles.

However, before we turn to this in more detail, we would like to consider the question to what extent the control can be alleviated by appropriate configuration selection. The external shape of a large ballistic missile consists of a nose section (which may be of conical or ogive shape, pointed or blunted), and subsequent cylindrical portions, either of constant diameter or sectionwise increasing toward the rear (the latter arrangement especially for multistage vehicles). The main parameter to be selected is the slenderness ratio. A simple consideration shows that the rigid body control situation is much more favorable for a long slender configuration than it is for a short stubby one. The necessary control deflection in a given wind situation is essentially proportional to the ratio C_1/C_2 of aerodynamic torque per unit angle of attack over control torque per unit control deflection. This ratio can—for a fairly long cylindrical fuselage—be approximately estimated by the formula given in Fig. 1.

The length of the fuselage drops out of the formula because, with our asumptions, it enters as lever for aerodynamic torque as well as for the control torque; but the square of the diameter remains since it determines the normal force. For a given mission, a certain volume of the missile is needed, and consequently, the diameter is proportional to the inverse of the square root of the length. Thus, from a control standpoint, it would be desirable to increase the length of the missile as far as practicable. Still better control ratios can be obtained by tapering because then an additional benefit is derived from a rearward shift at the center of pressure. Unfortunately, the selection of very slender configurations is not favorable with respect to structural conditions. Not only do bending torques resulting from wind loads and control action increase with increasing length, but also, even more undesirable is the reduction in stiffness which goes with growing slenderness ratio. Deformation of the airframe under the influence of aerodynamic and control loads represents a serious hazard to the operation of the control system because it will affect the input to the control system, and may easily give rise to unstable oscillations. This risk increases when the lowest natural frequency of the fuselage (usually the lowest bending mode is most critical) approaches the control frequency. A comfortable margin between these two frequencies is certainly desirable, since it reduces the need for very accurate analysis and prediction of factors, which are often difficult to establish prior to construction of a vehicle, and since it enhances the chance of safe operation of a fairly simple control system under flight conditions. What represents a comfortable margin between the frequencies (ratio of 3, 5, or even 10), and whether safe operation can be achieved at all with frequencies closely approaching each other are subjects of much concern to the designer of big missiles, and cannot be answered in simple terms.

Another complicating factor arises from the dynamic response of fluid propellants to missile motions which may, under unfavorable circumstances, saturate the control system. These phenomena tend to become

$$\ddot{z} = \frac{F-T}{m}\phi + \frac{N'}{m}\alpha + \frac{R'}{m}\beta \qquad (1)$$

$$\ddot{\phi} + c_1 \alpha + c_2 \beta = 0 \qquad (2)$$

$$\beta = a_0 \phi + a_1 \dot{\phi} + b_0 \alpha \qquad (3)$$

$$\alpha = \phi - \frac{\dot{z}}{V} + \alpha_w \quad (4) \qquad \alpha_w = \frac{w}{V} \quad (5)$$

WHERE z LATERAL DEVIATION FROM REFERENCE DIRECTION. (SPACE FIXED)

m MASS OF MISSILE

F THRUST

T TANGENTIAL AERODYNAMIC FORCE

N' SLOPE OF NORMAL AERODYNAMIC FORCE

R' SLOPE OF CONTROL FORCE

ϕ ATTITUDE DEVIATION FROM REFERENCE

α ANGLE OF ATTACK

V VELOCITY OF MISSILE

W COMPONENT OF WIND VELOCITY PERPENDICULAR TO FLIGHT PATH

β CONTROL DEFLECTION

a_0, a_1, b_0 GAIN FACTORS

c_1, c_2 AS DEFINED ON FIG. 1

Fig. 2. Linearized equations of motion for planar case.

$$\omega = \sqrt{\left[c_1 + c_2(a_0 + b_0)\right](1 - \zeta^2)}$$

$$\zeta = \frac{a_1 \quad c_2}{2\sqrt{c_1 + c_2\,(a_0 + b_0)}}$$

Fig. 3. Frequency of rigid body control mode.

more severe with increasing diameter of the propellant tanks. Whereas for missiles, such as the V2 and the Redstone, no sloshing phenomena were encountered, missiles of the diameter size of the IRBM and larger, require very careful analysis of those phenomena as some flight tests have painfully demonstrated, and the layout of a control system usually cannot be undertaken without consideration of fluid motions in tanks.

Rigid Body Control

In spite of the strong interactions between rigid body modes, elastic modes and propellant motions, it is worthwhile to analyze the problem in steps of increasing complexity, starting with the case of a rigid body restricted to motion in one plane. Interaction between motions around the three axes is usually small since the control system keeps angular velocities and angles small. For example, if we consider the motion perpendicular to the standard flight plane (yaw), the equations of motion can be written in the simple form shown in Fig. 2. The control equation is idealized by neglecting derivatives of β on the left side which produce phase lags increasing with frequency, but are not important for the basic argument. We notice that on the right side of the control equation a term proportional to the angle of attack has been added to the terms which indicate the attitude deviation (and its derivative) from a space-fixed reference (as measured by a free gyro).

The characteristic equation of these equations is of third order; two of its roots (usually conjugate complex) can be associated with the fast oscillation of the missile around its center of gravity; their frequency can be approximated with good accuracy by the expression given in Fig. 3. The third root describes essentially the response of the flight path (lateral drift) to wind. This root may be stable or unstable, according to the values of a_0 and b_0, the borderline case in between is obtained by setting the lowest order term in the characteristic equation equal to zero, which yields one root equal to zero and the relation set forth in Fig. 4. According to the definition of C_1/C_2, the right side of Eq. (6) can be expressed as Eq. (6a) (Fig. 4). If Eq. (6) is fulfilled, the missile assumes, in the presence of wind, an attitude which leads to cancellation of forces perpendicular to the undisturbed flight path; $\ddot{z}$ goes toward zero as soon as the transient oscillation around the center of gravity dies out; a component of thrust against the wind cancels the remaining lift force. This condition is called the "minimum drift control." For a stable configuration ($\Delta > 0$), Eq. (7) can be fulfilled by proper selection of a_0 only, b_0 may be zero; however, for unstable vehicles ($\Delta < 0$), the right side of Eq. (7) is positive and positive b_0 is required to obtain minimum drift control. If the left side of Eq. (6) is larger than the right side, the missile will turn its nose against the wind to such a degree that a positive acceleration takes place against the wind; the path root is unstable, and the flight path will continue to turn until the missile flies straight into the wind. Conversely, if the left side of Eq. (6) is smaller than the right side, the path root is stable, $\ddot{z}$ goes toward w, and the missile drifts with the wind.

If there is interest in minimizing the effect of winds upon the flight path, Eq. (6) can be fulfilled by time-programed gain factors; the right side of Eq. (6) is a function of parameters only which can be assumed known, and do not depend on the wind input proper.[1, 2]

An even more important aspect of angle of attack control is the beneficial effect upon control deflections in response to wind. They decrease with increasing b_0 or with decreasing a_0. Control requirements for an unstable vehicle of IRBM type with minimum drift control are only about 30–40 per cent of those with conventional control. However, further reductions can be obtained by permitting temporary path instability, making a_0 smaller, eventually even zero.

Such an approach may be indicated for highly unstable large missile configurations, where tremendous control torques and structural loads are involved. The deviation of the flight path in the presence of wind during the high dynamic pressure region is of little con-

$$\frac{b_0 + \frac{c_1}{c_2}}{a_0} = \frac{N^I - \frac{c_1}{c_2} R^I}{F - T} \qquad (6)$$

$$\frac{N^I - \frac{c_1}{c_2} R^I}{F - T} = \frac{h}{s}\,\frac{N^I}{F - T} = \left(1 - \frac{\Delta}{s}\right)\frac{N^I}{F - T} \qquad (6a)$$

$\Delta = s - h$ STABILITY MARGIN

FOR SWIVEL ENGINE CONTROL: $R^I = F$

AND FOR $F \gg T$:

$$b_0 = \frac{N^I}{F}\left\{a_0\left(1 - \frac{\Delta}{s}\right) - \frac{\Delta}{s}\right\} \qquad (7)$$

Fig. 4. Drift minimum condition.

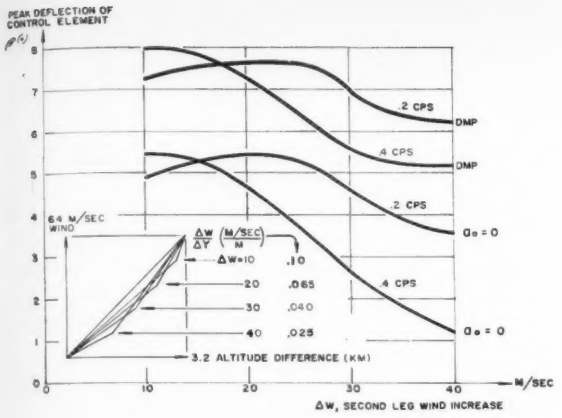


Fig. 5. Peak values of required control deflections for unstable missile in presence of strong wind increase.

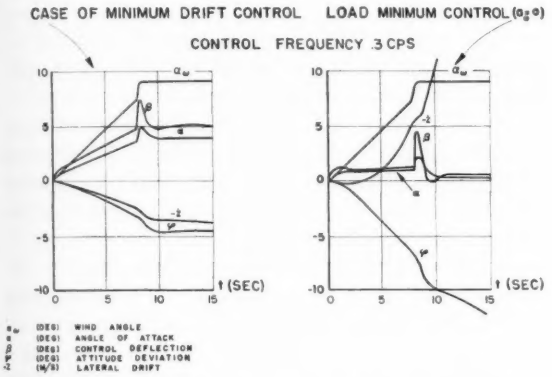


Fig. 6. Time response to wind rise according to Fig. 5 (second leg $\Delta W = 10 \times$ m./sec.).

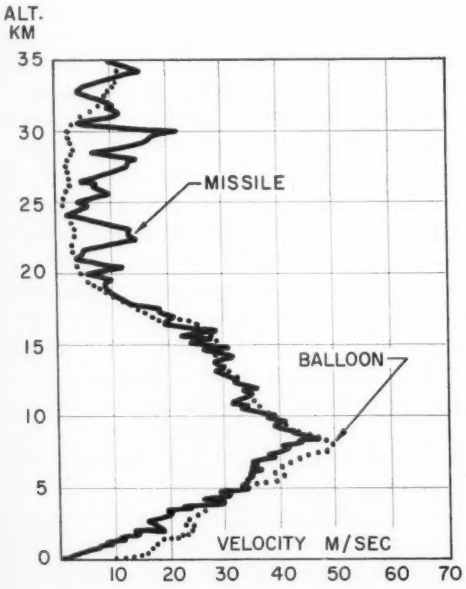


Fig. 7. Wind speed profile evaluated by angle of attack meters aboard missile as compared to wind profile obtained from balloon ascent. (Balloon released at missile launch time. Missile wind speed obtained in approx. 2 min.; balloon wind speed obtained in approx. 100 min.)

NATURAL FREQUENCY IN CIRCULAR CYLINDRICAL TANK:

$$\omega_n = \sqrt{b \frac{\epsilon_n}{r} \tanh\left(\epsilon_n \frac{h}{r}\right)}$$

$$J_1'(\epsilon_n) = 0$$

b=LONGITUDINAL ACCELERATION
r=RADIUS OF TANK
h=HEIGHT OF FLUID LEVEL
J_1'=DERIVATIVE OF BESSEL FUNCTION OF FIRST KIND

APPROXIMATE FORMULA FOR DAMPING (AFTER MILES):

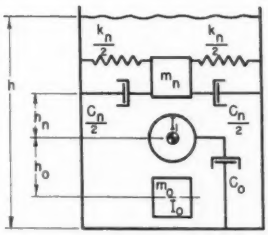
$$g = k \left(\frac{A_{BAFFLE}}{\pi r^2}\right)^{3/2} e^{-4.6 \frac{d}{r}} \cdot \left(\frac{\zeta}{r}\right)^{1/2}$$

$2.25 \leq k \leq 4.5$

r=RADIUS OF TANK
A_{BAFFLE}=BAFFLE AREA (ANNULAR RING BAFFLE)
d=DEPTH OF BAFFLE UNDER FREE FLUID SURFACE
ζ=FREE FLIUD SURFACE DISPLACEMENT AT WALL

TYPICAL BAFFLES FOR SLOSHING SUPPRESSION:

Fig. 8. Sloshing phenomenon.



$M = m_o + \sum_{n=1}^{\infty} m_n$ TOTAL FLUID MASS; $\omega_n^2 = \frac{k_n}{m_n} = \frac{b\epsilon_n}{r} \tanh(\epsilon_n \frac{h}{r})$

$C_n = \omega_n m_n 2\zeta$; $m_o h_o = \sum_{n=1}^{\infty} m_n h_n$

$$I_{eff} = I_o + m_o h_o^2 + \sum_{n=1}^{\infty} m_n h_n^2 = I_{SOLID} - I_1 \frac{1}{1 + \frac{C_o^2}{\omega^2 I_1^2}}$$

I_{eff}= MOMENT OF INERTIA OF LIQUID WITH FROZEN SURFACE

$$C_{eff} = \frac{C_o \omega^2 I_1^2}{C_o^2 + \omega^2 I_1^2}$$

FOR FINITE DAMPING I_{eff} AND C_{eff} ARE OBTAINED EXPERIMENTALLY

FOR ZERO DAMPING $I_1 = \frac{8mr^2}{h} \sum_{n=1}^{\infty} \frac{(\epsilon \frac{h}{r}) - 2\tanh\left[\frac{\epsilon_n h}{2r}\right]}{\epsilon_n^3(\epsilon_n^2 - 1)}$

Fig. 9. Mechanical model for sloshing analysis.

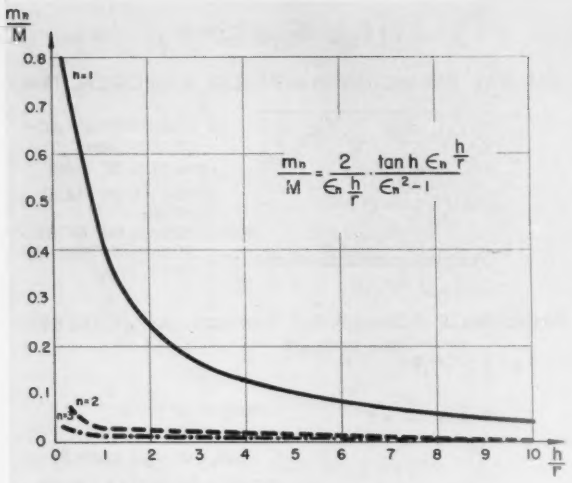


Fig. 10. Slosh mass ratio vs. fluid height ratio.

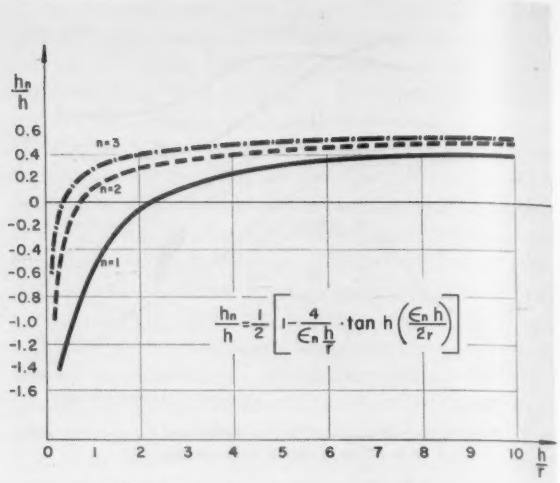


Fig. 11. Mass location height ratio vs. fluid height ratio.

cern, since it can be compensated by guidance induced maneuvers during the later part of propelled flight, when the missile has reached sufficient altitude to make it insensitive to aerodynamic effects. The actual determination of loads and selection of gain factors must be based upon analysis of transient reaction of wind, as well as consideration of quasi-steady equilibrium values, and this raises the question of the exact nature of the wind input which may be encountered. The dynamic response of the missile depends not only on size of the wind but also on its rate of change with time (which is essentially determined by the change of wind speed with altitude $\partial W/\partial y$). The interplay between mode of attitude control, control frequency, and nature of wind input is illustrated in Fig. 5 where the peak values of the control deflections of a large unstable vehicle during maximum dynamic pressure are shown resulting from wind increases, as illustrated in the insert on the diagram. In all cases, the wind rises from zero to a value of 64 m./sec. with the average shear of 0.02 (m./sec.)/m. The rise of wind is assumed in shape of a combination of two linear functions of different slope, and the increment ΔW of the second (steeper) part of the rise is selected as abscissa of the diagram. The wind shear, connected with the second leg, is also listed on the diagram. (The values correspond to about a 1 per cent probability.) Four curves are shown, two with gain factors such as to produce minimum drift conditions according to Eq. (6), and two with $a_0 = 0$. Each of the two modes is given for an (undamped) short-period frequency of 0.2 cps and 0.4 cps. The damping is 0.75 of critical damping. (The calculation of the response was performed assuming frozen coefficients—i.e., neglecting the change of such parameters as speed, dynamic pressure, etc., during the interval which corresponds to about 8 sec.) Each point of the curves then corresponds to the peak value of an individual event of wind rise. We see that

(a) Shear values of wind have an important influence on response, even though connected with relatively small absolute wind increases.

(b) Change from drift minimum mode to strict angle of attack control mode, $a_0 = 0$, produces a substantial reduction in control response, even though the control frequency is maintained. We may, therefore, call this mode "minimum load control."

(c) Selection of frequency has an influence on the control peak. With increasing control frequency, the peak response shifts toward smaller wind changes connected with high shear values. Selection of optimum control frequency (for load minimization) depends, therefore, on a knowledge of typical wind input. For the wind patterns assumed here, there results a minimum of largest peak response between the two frequencies shown. Time histories of missile response are shown in Fig. 6 for two typical cases.

For drift minimum control, the angle of attack assumes, after a short transient peak, a stationary value and so does the attitude. The lateral drift levels out at a modest drift with the wind.

For the load minimum case, the control-peak deflection is smaller, angle of attack goes toward zero, while attitude and lateral drift (into wind) are continuously increasing.

Further improvements in the transient peaks beyond the described system can be obtained, at least theoretically, by using the derivative of angle of attack instead of attitude angle in the control equation. A possible practical drawback to this solution may consist in the random input resulting from turbulent air or from aerodynamic noise around the fuselage, which tends to be amplified by differentiation.

Computations (or analogue runs) with frozen coefficients have the advantage of simplicity, and establish good approximations for gain factors. They have to be supplemented, of course, by more refined numerical work with inclusion of variability of all trajectory parameters. Fortunately, however, they do not produce

noticeable derivations in desirable gain factors (from the values obtained with frozen coefficients).

Wind Input

A more severe shortcoming is the lack of knowledge with regard to the wind input to be encountered. Wind is a more or less random phenomenon which has to be described in statistical terms. The use of wind profiles for control-response investigations has the advantage of simplicity, and gives a good insight into the operation of the control. However, in view of the complicated interplay between wind and control system, it is difficult to define a wind profile producing a load which has a strict statistical meaning (in the sense: this load will not be exceeded in say 99 per cent of all flights). Maximum wind speed (for a given probability level) or better mean values of wind and dispersion thereof can be given as function of altitude rather easily. A large amount of measurements is available which put this quantity on a well-founded statistical basis for altitudes up to about 30 km. Beyond that, altitude data are rather scarce and doubtful. According to application, geography and season can be considered as fixed, or can be averaged out, or deliberately chosen so as to give high values. (Substantial differences result from these approaches.) It turns out that pronounced wind peaks occur at an altitude around 10–13 km. (jet stream) which more or less coincides with the region of maximum sensitivity of most missiles (close to maximum dynamic pressure region). Unfortunately, the same amount of information is not available with respect to wind shear and gusts. Evaluation of wind shear from wind soundings with balloons suffers from several shortcomings, among them the following:

(a) Response of balloon is too sluggish for fast wind changes (of small scale).

(b) Height intervals for evaluation are mostly too large for accurate shear evaluations (1–2 km.). Large-scale evaluation tends to smooth out wind peaks.

(c) Inaccuracy of measurements—e.g., inaccuracy of tracking—has strong influence upon shear evaluation.

Several efforts are under way to improve the situation by better tracking methods, and/or use of new measuring devices (such as drop sondes, smoke signals, observation of sound propagation, doppler effect on scattering of electromagnetic waves, etc.). Interesting results have also been obtained by evaluation of winds from angle of attack measurements, missile attitude measurements, observation of flight path direction and missile speed from the ground. These quantities define the wind input (if we assume the wind to be strictly horizontal). Comparison of such evaluations with balloon measurements have been carried out on a number of missile flights. A typical example is given in Fig. 7. It shows clearly the smoothing effect of the conventional procedures. A systematic statistical evaluation of these missile-measured winds for shear values has not yet been carried out. The wind shear values given in Fig. 5 have been constructed upon evaluation of balloon ascents at Patrick Air Force Base with 1,000-mile-height intervals and correspond approximately to a 1 per cent probability. These wind shear values can then be used, together with the peak wind values (around the critical regions), to construct a synthetic critical wind profile. A more thorough statistical approach than the construction of critical profiles consists in description of the original soundings by mean values of both wind components and their dispersion for all altitude levels, as well as the correlation of their variations from mean wind components at various altitudes and between both components.[3] The matrices of means and correlation coefficients can be combined directly with the matrix of the missile responses at various times to a given disturbance impulse and thereafter. This furnishes then the mean and variance of the missile response.[4, 5] This method has the advantage of giving statistically better defined answers with immediate incorporation of time variability of the system parameters. The numerical effort in obtaining these values is, of course, substantially larger than the previously described methods, and it will be advisable to use this procedure only after the approximate methods have established the desirable set of gain factors rather closely. (*Continued on page 68*)

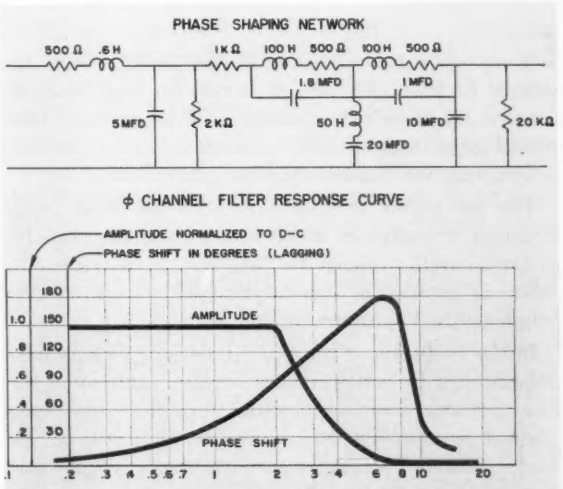


Fig. 12.

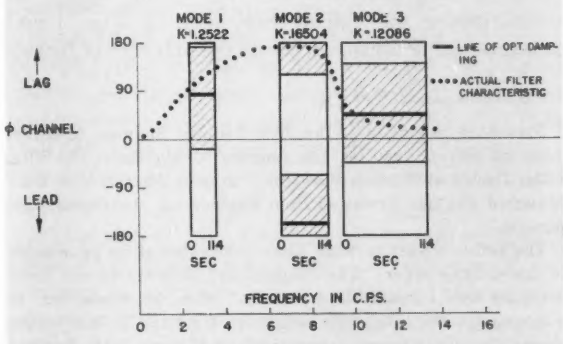


Fig. 13. Stability region and filter characteristic.

Design of Jet Transports With Rear-Mounted Engines

"By 1965, the traveling public will be able to fly in the 'new look' in aviation, across the Atlantic, across the Pacific, in Europe, in America, and around the world if they wish."

D. J. Lambert, AFIAS, *Vickers-Armstrongs (Aircraft) Limited*

ENGINE LOCATION on aircraft has tended from the Wright Brothers' first design to vary for many reasons, usually, all essentially practical. Engines have been placed for reasons of safety, reasons of balance, reasons of structure weight, aerodynamic purity, etc.

The jet engine is unquestionably the most easily mounted primemover which has been made available to the aircraft designer to date and, as a result, the choice of positioning can be dictated more than ever before by the "optimum for the job."

In the evolution of the V.C. 10 design, Vickers were unhampered by any previous family requirement demanding that existing facilities, existing data, or a "logical development of a current military type" be used. Vickers' jet experience embraces single- and twin-engined pure jet-fighter types with body-mounted engines, and the Valiant bomber with paired engines in the wing roots. The important characteristic of all these designs is that they are "clean wing." A comparison of the Valiant and the B-47 (Figs. 1 and 2) is interesting because it shows the influence of British short-airfield requirements in comparison with the U.S.A. military "miles of concrete" designs laid down with very similar objectives. The V.C. 10 (Fig. 3) is typical of the rear engine layout discussed in this paper, and was developed originally for the Empire routes of BOAC, and was strongly influenced, similarly, in the direction of high-lift and optimum aerodrome performance. The Sud Aviation Caravelle (Fig. 4) at this time was beginning to show its potential, and the fact that its fundamental layout did not seem to present any major problems was obviously reassuring.

Mr. Lambert is Assistant General Manager (Development) for Vickers-Armstrongs (Aircraft) Ltd., and has been associated with this organization for all of his 20-year professional career. In recent years, the author has become widely known for his close connections with the design and economic development of Vickers commercial aircraft. His association with the Viscount, Vanguard, and V.C. 10 has been an intimate one. In addition to his affiliation with the IAS, Mr. Lambert is an Associate Fellow of the Royal Aeronautical Society, and an Associate Member of the Institution of Mechanical Engineers.

In the case of the V.C. 10, it was realized that the fundamental drawback with such a design was its inherently higher empty weight, a penalty which, it is important to note, is more than compensated for in aerodrome performance by the higher lift.

At the time of committing the V.C. 10 design to the normal process of detailing and manufacture, there was considerable heart searching in order to ensure that the right road was being embarked upon in view of the heavy outlay to which the airlines were already committing themselves on the interim first generation of large jets.

Presented originally at the IAS National Summer Meeting, June 28–July 1, 1960, at Los Angeles, Calif., under the title, "The Design of Modern Pure Jet Transport Aircraft with Rear Mounted Engines Reviewed from Engineering and Operational Aspects."

The author wishes to thank Vickers-Armstrongs for permission to present this paper. The opinions and facts stated are, however, his own responsibility entirely. Also, he would like to acknowledge the invaluable assistance rendered to him in the preparation of the paper, in particular by Messrs. N. A. Barfield and M. R. Fountain, as well as by various other members of the design staff of the firm.

FIG. 1. VICKERS VALIANT

FIG. 2. BOEING B.47

FIG. 3. VICKERS V.C.10.

FIG. 4. SUD AVIATION "CARAVELLE"

As the program has developed, the correctness of the decision has been amply justified. There seems no reasonable doubt that the next generation of subsonic pure jet aircraft introduced into service in the middle to late 1960's will have a similar layout.

For these reasons it seems worth while to attempt to set down the author's thinking on the pros and cons of such a layout.

Although there are designs which incorporate two-side fuselage-mounted engines, and one buried engine in the tail fuselage, the author excludes these from his pro and con argument—when the arguments have been reviewed, the reasons should be fairly obvious. The side-mounting concept, be it with single or paired power units, is the subject of the paper and the "local" arguments around the pairing of power units are dealt with as a complete section of the paper.

It is necessary, for comparative purposes, to assess the advantages and disadvantages against those of another typical layout. The currently "conventional" podded installation of the Boeing 707, the DC-8, and the Convair 880 series has been accepted as the yardstick against which the rear engine arrangement should be assessed.

Although there are some very successful civil aircraft, such as the Comet IV, with buried engines, it is the author's opinion that the long-term development potential of such a layout is limited and should not form the basis of a comparison.

Earlier papers on the subject by Sud Aviation, and in a slightly different vein by Lockheed, represent an excellent survey of the potential advantages of specific applications of the layout. This paper is intended to deal with the matter on a broader base.

Structural Design

The structural design of the rear-mounted concept does not present any fundamentally new problems. It does call for some new thinking, however, in particular in rear fuselage strength between the engines and the wing attachments, and also locally in terms of engine attachment to the fuselage.

Facing up to the high rear fuselage shear loads resulting from the landing and flight inertia cases automatically means that problems of pressure-cabin fatigue in this area become less important than hitherto. In the case of the V.C. 10, it was decided to design the cabin window cutouts integrally as a section of machined skin, as shown in Fig. 5, to give an optimum answer in terms of strength, weight and fatigue-worthiness.

In the case of the engine mountings themselves, the design and attachment of the support structure is analogous to that of a conventional, structurally redundant two-spar torque box-wing body combination, except that the structure itself is subjected to considerably less bending fatigue than that of a conventional wing.

Engine detachment in the event of a controlled crash or conventional survivable belly-landing cannot be tolerated in this layout and the engine mountings and attachments are, therefore, designed to the full crash inertia cases. This means that in various areas the safety factors of the engine mounting structure are well in excess of those required to meet the flight cases. To put it another way, "more of the structure is in less doubt."

Dynamic overswing cases, engine nodding loads, etc., have in addition always been something of "an extra problem," both on aircraft with long slender nacelles, such as the Viscount, and on podded wings relying for their integrity on bending relief. Their elimination appears to have some merit.

It is interesting to note that approximately 90 per cent of the world's high-speed jet aircraft manufactured to date have had clean wings and, hence, structural design of high-speed wings is clearly one in which the greatest proportion of experience is available on those free from engine mounting complications. It should also be noted that the maneuver design criteria on current fighter aircraft, such as F-86 and the Hawker Hunter, of 12g or more, compare with the 3.75g requirement for civil transport aircraft, and effectively scale the clean fighter wings into the same design structure category as that of the clean wing transport of say 300,000 lbs.

As has already been said, there are weight reductions possible on podded wings, and the performance and economic success of the current generation of large pure jets undoubtedly is dependent upon these savings to a considerable extent. The rear-engined layout with its lack of wing-bending relief calls fundamentally for a

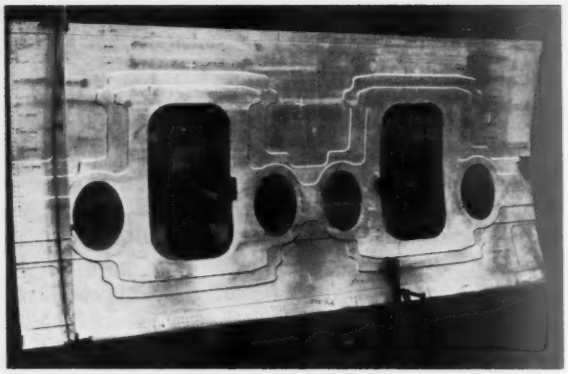


Fig. 5. Integrally machined panel as used in the V.C. 10 fuselage structure.

heavy wing, and experience with both flexible wings and stiff wings leads one to the belief that the long-term maintenance and overhaul costs of the latter will be significantly less than those of the former. It will be several years before the full implications of current design trends are felt in terms of structural maintenance, but it seems clear that rear engines and clean wings are a step in the right direction.

T (Top) Tailplanes

As will be seen in the section devoted to aerodynamics, there are considerable arguments in favor of the top-mounted tailplane from the all round optimum aerodynamic aspect.

Accepting the requirement for the moment, the structural implications are straightforward: an important set of loads have to be transmitted through a joint; the base is somewhat limited; therefore, a bit more meat and fail-safe characteristics—i.e., redundancy of structure—are required. This is a normal design problem which structural designers worldwide are called upon to solve regularly.

As regards flutter, there can be no doubt that the high tailplane and the relative flexibility of the fin and the attachment calls for cautious and detailed evaluation. From the airline point of view, flutter these days is a problem which they (and the airworthiness certifying authorities) expect the manufacturer to solve before delivery. It is a safe bet that all major designs, either in service or coming into service, have been through their flutter "crises" either in the air or on paper during their evolution. Few of these incidents, naturally enough, are publicized unless the visible damage on landing is such that the story, which is bound to be circulated, will become more lurid without explanation than with explanation.

There have been, to the author's knowledge, two types of relatively recent high-tailplane aircraft which have had serious trouble. One of these problems was associated with actuator runaway—and would have been equally catastrophic in any other tailplane position. The other was a flutter problem and has, as is usually the case with aeronautical progress, exposed the design factors and critical parameters, knowledge of which should enable the designers to prevent recurrence.

On the pure credit side structurally is the fact that the tailplane is well clear, not only of downwash and its associated turbulence, but also of noise-damage effects, and the areas affected are clearly much less troublesome than on either the "buried" installation or the podded one. Figs. 6 and 7 are drawn to the same scale and represent typical rear engine and typical podded engine installations, together with the same *datum* noise cones superimposed.

Structural Weight

Clearly, the various structural problems discussed in the foregoing paragraphs account for the unquestionable fact that the empty weight of a given rear engine design will be somewhat higher than that of its podded contemporary. There are some compensating weight advantages when systems layout and maintenance features are considered in detail, but the end result would still appear to be somewhere between 2 per cent and 4 per cent of the empty weight against the rear-engine layout.[1] However, each of the structural problems which contribute to this weight percentage in its turn results in a more than balancing aerodynamic gain.

Aerodynamics

The advantages of the clean wing, both from a high Mach number cruise-performance aspect and an optimum lifting surface point of view, are almost too well known. Comparisons of maximum lift, between different manufacturers' and different licensing authorities' points of view, are fruitless as anyone who has compared manufacturers' brochures will agree. The way to assess clean wings against podded wings is on the basis of a given standard of design—i.e., figures for comparable designs produced by one design team simultaneously. Fig. 8 has been derived as a result of precisely that exercise and shows what can be done with a clean wing compared with a podded one in terms of approach speed, and it gives a practical illustration of the significance of the lift which is lost by flap cutouts, pod interference, etc.

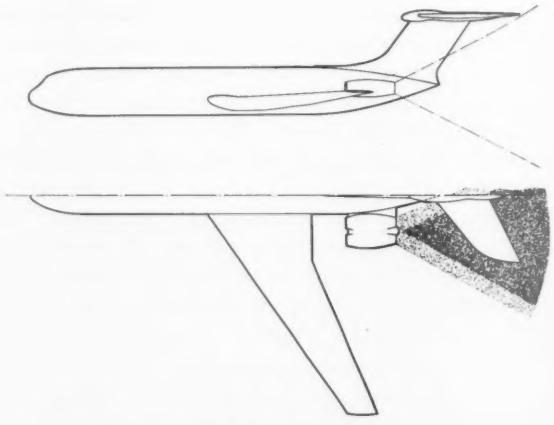


Fig. 6. Noise cone. Rear-engined layout.

The example superimposed on the figure, assuming a typical landing weight of a current big jet of say 200,000 lbs., shows that the extra lift of the clean wing would permit 25,000 lbs. extra landing weight for the same approach speed (or landing distance). The extra empty weight resulting from the rear-engine design is, say, of the order of 3,000 to 5,000 lbs. and thus a bonus equivalent to at least 20,000 lbs. of weight is available, either for reducing approach speed and landing run or permitting the design to be based on a significantly smaller wing area. Fig. 9 shows the effect of varying the wing area on a typical medium-range jet transport, both under high-speed short-range cruise conditions at 20,000 ft. and under long-range cruise conditions at 35,000 ft. It will be seen that the saving in wing area, which the rear-engine layout permits, makes a most important contribution to reducing the total route fuel consumption. Clearly, the percentage effects will vary with different designs, but the overall effect is unlikely to be markedly different.

In designing for higher Mach numbers, there is little doubt that any aerodynamicist would prefer to start with a clean pair of wings than a podded set, and would be happy to forecast greater accuracy in his predictions. Again, the reader's attention is drawn to the fact that probably 90 per cent of the world's experience on the performance achievement of high-speed airplanes comes from clean wing fighter designs.

Aerodynamically, it is difficult to find any aspect of rear-engined design that is more difficult than with podded engines. The problem of the wing/pylon intersection on the latter certainly equals that of ensuring that the rear-mounted engine intakes are clear of the fuselage boundary layer and that the "gulleys" between the inboard and outboard engines are not critical. While the well-known up-flow in front of the wing, Fig. 10, increases the intake problems of wing-mounted engines at high angles of attack, the converse applies in the case of rear-mounted engines, Fig. 11.

This same downwash phenomenon acts equally in support of the high tailplane positioning. Wing down-

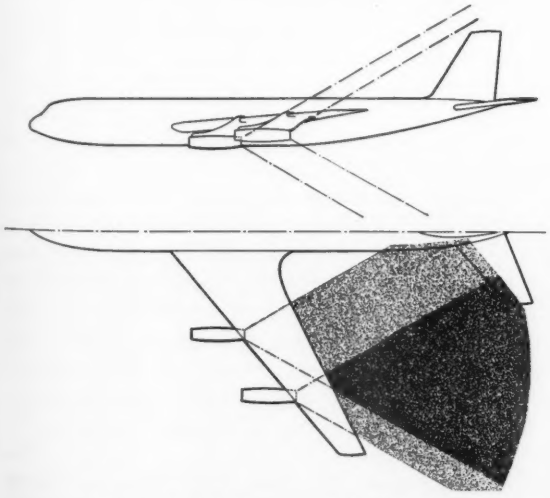


Fig. 7. Typical noise cone. Podded aircraft.

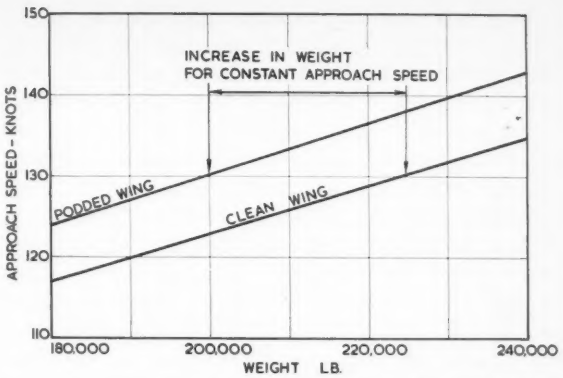


Fig. 8. Approach speed (constant wing area), clean and podded wings.

wash over the tailplane is fundamentally a destabilizing function in the longitudinal plane, and its effect obviously diminishes as the height of the tailplane is increased.

In the case of the transport designs with which the author is familiar, the critical aft stability limit is fixed by a high-speed case and, under these conditions, the extension of the aft limit in terms of s.m.c. is of the order of 8 per cent (18 in. on a typical big jet s.m.c.) purely as a result of the shift of tailplane vertically from the fuselage centerline to the top of the fin.

In the low-speed case, with swept wing aircraft, "pitch up" is a problem which is virtually eliminated by the high tailplane position—conversely, in the fuselage centerline position, the tailplane would normally be destabilizing under such conditions.

Elsewhere in this paper the required c.g. range of the rear-engined aircraft from the operational point of view is discussed. However, to the aerodynamicist, another important feature of the high set tailplane is that its geometric position on the top of the fin ensures an automatic bonus on tail arm which, coupled with the reduction in the destabilizing effect of the downwash, ensures that the wide c.g. margins inherent in the design are permissible without anything abnormal in the way of tail size. Quick reference to the outline overlay of the V.C. 10 and the Boeing 707/120 shows that the tail arm and geometric layout are surprisingly similar, Fig. 12.

Although, theoretically, some problems might be expected with the critical Mach number characteristics of the tailplane/fin intersection, tunnel tests have shown these to be groundless on the V.C. 10 and subsequent developments. This is basically because the low-aspect ratio fin and the tailplane design lend themselves to a wide separation of their peak velocities. The relatively large "bullet" fairing, which can be seen at the V.C. 10 tailplane/fin intersection, is there to house the incidence change mechanism rather than from aerodynamic necessity. The aerodynamicists provisioned it in their original planning and, naturally, the structures engineers made full use of it. When the aerodynamicists offered to withdraw their requirement, they were told that this would not be in the general interest!

After experience of cruciform tailplanes and having seen them in production for some years, it can be said, with little hesitation, that they represent the worst of both worlds. Quite apart from the simplification of the fairing of the moving tailplane mechanism itself, and the easing of the "junction" aerodynamics, the top-mounted tailplane is a valuable "end plate" on what could thus be a very low-aspect ratio fin (1.08 for the V.C. 10 based on net area). This, in part, explains why the structural problems of tailplane mounting and fin stiffness are so much less than commonly supposed for such a design. The gain in effective fin-aspect ratio, due to a top- or bottom-mounted tailplane, is of the order of 40 per cent compared with the cruciform design. Visual inspection of some current designs is of interest. (See Fig. 13.)

The small asymmetric yawing moment of Nos. 1 and 4 engines in the rear-mounted design is also important aerodynamically in that it presents no fin design requirement as such. The fin area is designed by the cross-wind landing case. This, in its turn, is an important "plus" because it does mean that the usual thrust development of most jet-engine types can be absorbed without increasing either the fin loads or the fin area, while the progressive increase of by-pass ratios and their attendant increases in engine diameter can be better accommodated at the side of a fuselage than under the wing, where the designer is bedeviled by problems of wing/pod interference above him and pod/ground interference below him.

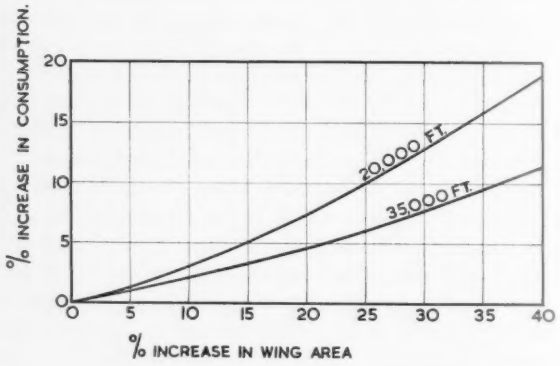


Fig. 9. Effect of wing area on consumption.

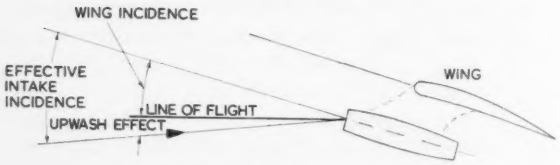


Fig. 10. Effective intake upwash—podded engines.

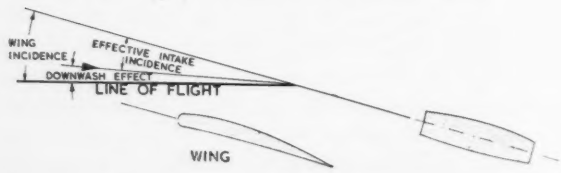


Fig. 11. Effective intake downwash—rear engines.

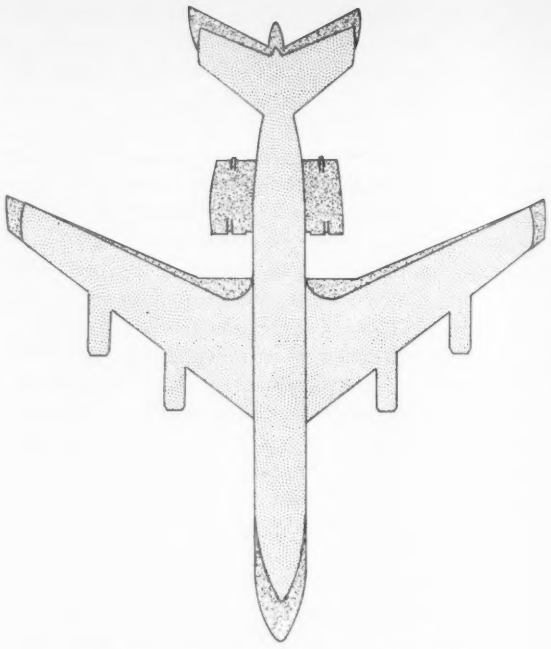


Fig. 12. Vickers V.C. 10 and Boeing 707/120.

Boundary-Layer Control (BLC)

In the author's view, one of the major advances in aerodynamic technology, which will provide real operational benefit to the airlines in the next decade, is the use of BLC for lift augmentation. BLC will carry with it a simultaneous demand for systems simplicity and fail-safe dependability. Let us assume that in a four-engined aircraft BLC by flap blowing is obtained by the utilization of bleed air from each of the four engines, and that the failure of one will result in no loss of lift and the failure of two will be known, but will not be physically significant to the pilot. Obviously, such a system demands a manifolding and cross-feeding system which, to say the least, on an airplane with engines spread from "tip to tip," represents severe duct losses and complexity.

As has been said in the systems section, there are considerable simplification benefits in grouping the power units in one area. Fortuitously, such an arrangement may well establish in an unmistakable fashion the airline practicability and desirability of BLC in the next few years.

Clarence L. Johnson[1] refers to early experiments with the use of boundary-layer control on the JetStar. These were abandoned because of the lack of adequate air in the approach regime and the relatively low-pressure ratio of the engines which were being used. The continuing increase of engine pressure ratios is obviously another important contribution to the author's view that the next few years will make BLC a development which every operator will demand on his new jet aircraft. Although a less obvious advantage of the rear engine layout than some of the others, the automatic simplicity of the continuous flaps, which are pos-

sible with the rear engine design, means that ducting air to the flaps in a "fail-safe" manner becomes more straightforward and significant system savings are possible.

Systems Engineering

With rear-mounted engines, the whole of the empennage structure is naturally high set to cater for the normal range of landing attitudes as in any other type of layout. The landing ground attitude and landing gear configuration (i.e., adequate track coupled with the use of the fuselage for stowage if the gear folds inboard) are really the only parameters governing ground clearance. The height of fuselage-mounted engines thus ensures the added benefit of very satisfactory ground clearance to avoid debris and slush ingestion, to reduce the pavement blast problem, and to give unrestricted maneuvering area and safety to ramp operators, when engines are running. Typical ground to intake lip heights on the V.C. 10, and on an equivalent pure jet of conventional design, are $12^1/_2$ ft. and 3 ft., respectively. Obviously, the resulting working height of the former is more of a problem than is the case on an underwing podded installation. This is compensated for, in the author's opinion, by the concentration of the system and maintenance and servicing requirements into a small area rather than having, say, Nos. 1 and 4 engines separated by some 35 yards.

Balance considerations dictate the relative position of the major components, and the resultant wing position closer to the engine location makes system runs

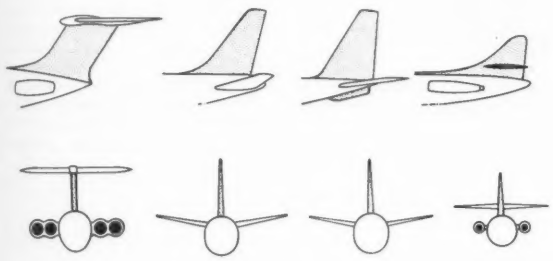


Fig. 13. Typical fin shapes.

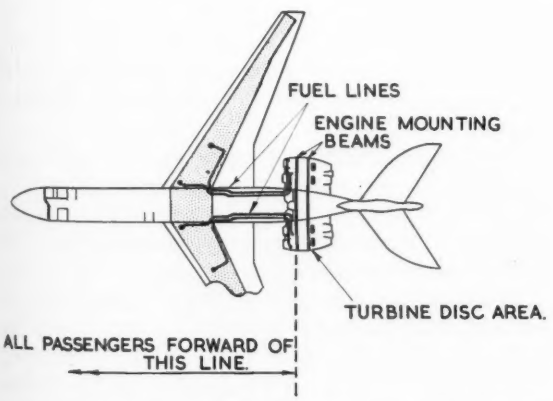


Fig. 14. Layout of fuel system engine mountings, turbine discs, and passenger area.

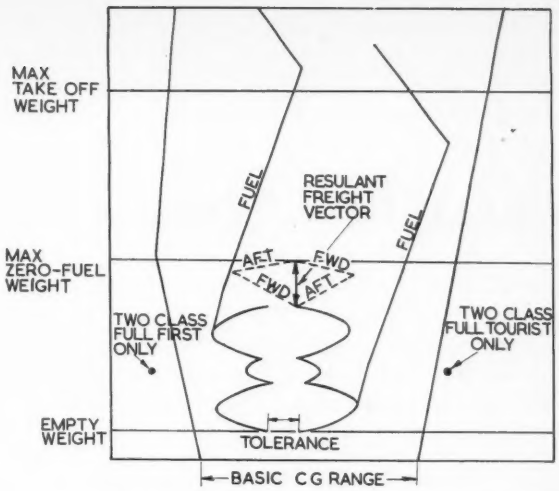


Fig. 15. Typical "podded" loading diagram; window seating first

short and simple, particularly with the greater concentration of both the generation and supply ends of the respective circuits.

With electrical looming running as it does into many miles in modern transports, the benefits over a layout with widely spaced underwing engines are obviously significant. The layout lends itself well to the logical development of the modern concept of discrete system service centers.

Overall balance considerations enable a compact equipment bay to be provided between the forward freight hold and the nosewheel bay, to house all electrical, radio and electronic equipment in a position ideally suited to ground maintenance and 'in flight' access (adjacent to the flight deck).

The natural concentration of the other systems components in the rear fuselage with common access is of considerable benefit to ramp and maintenance staff, both for routine trouble shooting and removal and overhaul.

Safety

Safety is a subject in which the author feels it is both unethical and unwise to make comparisons between aircraft types. However, either through competitive prejudice or through ignorance, a number of doubts about rear-engined installations and about paired installations have been put into aeronautical circulation. In the designs with which the author has been connected, there seems to be a good case for making a challenging and blunt statement about the true facts—the comparison with other designs can then be made by the reader. Reference to the schematic Fig. 14 is helpful here.

The major doubt in many people's minds is the supposed increased risk of interrelated mechanical engine damage. In the event that the oft discussed turbine disc or 'wheel' failure occurs, there is an arc within which the second engine will be affected. To get this into

(*Continued on page 72*)

PROJECT SCORE—The first satellite communication system

Use of satellites for communication purposes has been and is a subject of considerable study by military and commercial organizations in the communications field. The Score experiment, the first successful satellite communication system, is discussed here.

George V. Kedrowsky

U.S. Army Signal Research and Development Laboratory

At 6:02 P.M. EST, December 18, 1958, the Atlas 10-B Intercontinental Ballistic Missile majestically rose from a launching pad at Cape Canaveral, Fla. (Fig. 1). Within minutes, information came back from the tracking computer equipment that the predicted target impact area was infinite; this was the first indication that the Atlas satellite was in orbit. After the first dozen passes, the apogee was about 928 miles and perigee about 115 miles with an orbiting period of 101 min. The orbit achieved was slightly less circular than desired. Anticipated apogee and perigee were 625 miles and 118 miles, respectively.

Of the initial 224,000 lbs. of the Atlas, 8,750 lbs. (of which 142 lbs. were payload) were placed into orbit.

At the turn of the century, Marconi established a radio communications link which spanned the Atlantic Ocean. Now, slightly over a half century later, the use of earth communication satellites to relay radio signals around the world has been proved.

Project Score (Satellite Communications by Orbiting Relay Equipment) was the first of a series of communication satellites which will extend radio range, increase traffic flow around the world, open up a whole new region of the radio spectrum (microwave), and also provide new forms of reliable transmission of television, teletype, and voice.

The subject matter of this paper has been discussed with several of the persons who also participated in the Score project, and the author has been greatly benefited by their comments. The author wishes to express his thanks to all those individuals who generously gave of their time during these discussions.

Mr. Kedrowsky of the Advanced Development Group of the Astro-Communications Branch, U.S. Army Signal Research and Development Lab., works directly with communication satellites and associated systems. He holds a B.S. degree in electrical engineering from Rutgers University and has taken advanced courses in electronics and communications. While employed by Gulton Industries, Inc., he specialized in the design and development of magnetic tape recorders and associated instrumentation equipment for missile application. In 1958, he joined the U.S. Army Signal Research and Development Lab., Ft. Monmouth, N.J., where he was engaged in the design, development, and fabrication of the Score satellite. Subsequently, as a Senior Electronics and Project Engineer, he has been active in the development of advanced communication techniques for satellite application. Mr. Kedrowsky is a member of the IRE.

Experiments

In July, 1958, an Advanced Research Project Agency established at the U.S. Army Signal Research and Development Laboratory an expedited program to design, develop, and fabricate a communication package to be installed aboard an Atlas Intercontinental Ballistic Missile.

The communication package was basically a delayed repeater with the capability of real-time operation. Due to these capabilities, a number of significant communication experiments were performed during the short life of the satellite.

Varied combinations of voice and teletype transmission and reception were performed between the satellite and a network of four communication sites. The sites were located at Prado Dam Basin, Corona, Calif.; Army Electronic Proving Ground, Ft. Huachuca, Ariz.; Ft. Sam Houston, Tex.; and Ft. Steward, Ga.

Fig. 1. Atlas 10-B ICBM.

(Fig. 2). A temporary fifth site was located at Cape Canaveral for prelaunching checkout and preliminary checkout for the first few days in orbit. It was this site which interrogated the satellite on December 19 and received the first message transmitted from the satellite. The message received was:

> This is the President of the United States speaking. Through the marvel of scientific advance, my voice is coming to you from a satellite circling in outer space. My message is a simple one. Through this unique means, I convey to you and to all mankind America's wish for peace on earth and good will towards men everywhere.

Experiments performed included the following:

(1) Initially, transmission of President Eisenhower's message in voice followed by one channel teletype code, using delayed repeater.

(2) Direct relay of California's communication site identification in voice, followed by the President's message in teletype code. This was the first successful relay of teletype signals through an orbiting station. The Texas site received these signals with two short fades (probably due to tumbling of the Atlas) and the Arizona and Georgia sites received some signals.

(3) While clearing the tape recorder, California transmitted in voice to the satellite for storage. Texas interrogated the satellite, and both Texas and Georgia received the voice loud and clear. Then Georgia reinterrogated the satellite and received the message again. This was the first successful delayed repeater communication from earth to satellite to another point on earth at a later time.

The above tests were performed in other variations using voice and one channel of teletype until the fortieth pass, when the Georgia site sent seven simultaneous multiplexed teletype code transmissions to the satellite for storage. The satellite was then interrogated and good teletypewriter copy was received. This was the first successful multichannel teletype transmission by delayed repeater. Thus, the feasibility of communication satellites was proved.

All the activities of the four communication sites were coordinated at Control Central, which was at the Signal Corps' Astro-Observation Station, Deal, N.J., by means of a high-frequency interstation net using AN/GRC-26 radio system.

Considerations

The communication transmitters in the satellite operated on 132.435 and 132.095 mc., while the receivers operated on 150.735 and 150.225 mc. These frequencies were chosen in this band to avoid cosmic noise, ionospheric propagation phenomena and also to permit the use of transistorized receivers. The intermediate frequency bandwidth was kept as narrow as possible, being consistent with maximum audio frequency, deviation, Doppler shift and oscillator stability.

The deviation ratio was 1.0 at 5 kc., which required passing only the first sideband for reasonably distortion-free reception.

Based on a predicted orbital velocity relative to earth, maximum Doppler frequency shift was calculated to be ±4 kc. per sec.

The oscillator stability of the satellite was ±0.005 per cent.

Receiver power for ground to satellite was calculated as follows:

$$P_R(\text{dbw.}) = P_t - 37 - 20 \log d - 20 \log f + G_t + G_r - L_x$$

where

P_t = power output in dbw.
d = path distance (mile)
G_t = transmitter antenna gain (over isotropic)
G_r = receiver antenna gain (over isotropic)
L_x = insertion loss

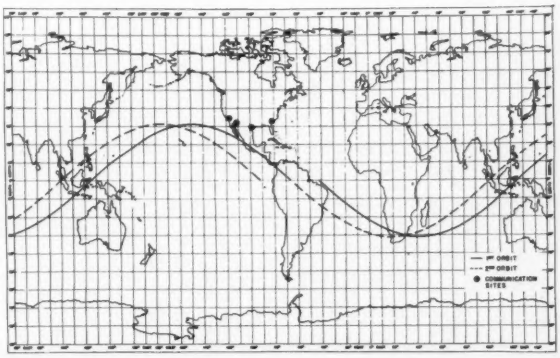


Fig. 2. Communication sites and satellite orbit.

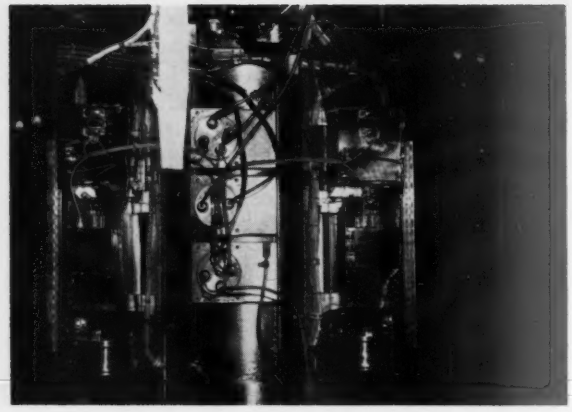


Fig. 3. Equipment in pod. Score satellite communication system mounted on Atlas 10-B missile.

Fig. 4. Location of pod on Atlas body.

The path distance from ground to satellite was considered to be 1,000 miles. L_z includes insertion loss of transmission lines, diplexer and filters, and ring isolators in the satellite. Cosmic and solar noise was considered to be 5 db. at 150 mc. per sec. and 7 db. at 130 mc. per sec. Therefore,

$$P_R = 30 - 37 - 20 \log 1{,}000 - 20 \log 150 + 16 - 1 - 2 = -98 \text{ dbw.}$$

Receiver noise power for ground to satellite was calculated as follows:

$$P_N(\text{dbw.}) = KTFB = -144 \text{ dbw.} + F + 10 \log B$$

where F = noise figure, including cosmic noise in db., and B = IF bandwidth in mc. per sec. Therefore,

$$P_N = -144 + 11 - 14 = -147 \text{ dbw.}$$

Therefore, carrier to noise = 49 db.

This allows ample margin above the FM threshold to ensure reception of command tones by the receiver in the satellite.

Receiver power from satellite to ground was calculated as follows:

$$P_R = 9 - 37 - 20 \log 1{,}000 - 20 \log 132 - 1 + 14 - 3 = -120 \text{ dbw.}$$

Receiver noise power from satellite to ground was calculated as follows:

$$P_N = -144 + 9 - 14 = -149 \text{ dbw.}$$

Therefore, carrier to noise = 29 db.

Of this amount, 10 db. was the minimum acceptable signal, and 19 db. was for null compensation in the antenna pattern of the satellite and also for an expected drop in battery voltage.

Satellite Equipment

Two complete systems were employed to increase reliability, thereby guarding against a disastrous failure. The 142-lb. payload consisted of two duplicate packages in what normally are the guidance pods on the sides of the Atlas body (Figs. 3 and 4). Each package contained a receiver, transmitter, magnetic tape recorder, control unit, beacon transmitter, d.c. to d.c. converter, and battery (Fig. 5 and Table 1).

The transistorized receiver, from a belt-mounted two-way FM paging radio, was enclosed in a special shock resistant covering. It was modified to increase its radio frequency sensitivity and to ensure operation under the new environment. The increased radio frequency sensitivity was accomplished by adding a radio frequency stage employing selected transistors, thus lowering the front-end noise figure by about 10 db. A transistorized relaxation oscillator was employed as a "battery saver," which served as a switch in series with the receiver. When no signal was present, the receiver would be on for 0.25 sec. and off for 2.5 sec. Upon receiving a command signal, the "battery saver," would remain on; when this signal ceased, it would return to on-off operation. By employing a "battery saver," power drain was reduced by 90 per cent during stand-by operation.

A vacuum tube transmitter from an FM handie-talkie was repackaged and modified. Repackaging entailed mounting for shock, vibration, and heat transfer. A high-power output stage was added to provide 8 watts.

A continuous loop magnetic tape recorder developed at the U.S. Army Signal Research and Development Lab. was used as the storage device. Direct recording techniques were employed, and, as a result, the electronic circuitry consisted of a record amplifier, playback amplifier, and a bias-erase oscillator. Two specially designed heads were used, a record/playback head and an erase head. To provide an audio bandwidth of 300 cps to 5 kc. per sec., tape speed was $3^3/_4$ in. per sec. Seventy-five ft. of magnetic tape, lubricated on one surface, was used to provide 4 min. of recording. The entire tape transport was sealed so that it would remain at atmospheric pressure. This was necessary to prevent the lubricant on the ball bearing from boiling off. After a 4-min. cycle, an automatic stop placed the entire system into stand-by, thus reducing the necessity of an additional command signal. This was accomplished by means of a 1/2-in. metallic splice on the

tape which completed an electric circuit once every cycle.

The control unit responded to command signals from the ground and activated the receiver, the transmitter, or the magnetic tape recorder. Three modes of operation were commanded—record, playback, and real time. Stand-by was automatic (see above).

Special notch filters were used to detect various tones to command the satellite. In the record and playback operation, latch-type relays were used. They switched to the desired mode upon command and remained in this position until the automatic stop unlatched them at the end of the 4-min. cycle. These relays were necessary because if the system was not turned off after passing over a communication site, the system might operate for an entire orbit and thus drain the battery.

In real-time operation, the recorder was by-passed and direct relay employed (receiver to transmitter). A conventional relay was activated by a continuous tone. When the satellite would get out of range, the signal faded and stand-by operation resumed.

In stand-by operation, all equipment was off except the beacon and the receiver, which was operating on the "battery saver."

The transistorized 30 mw. beacon transmitter, similar to those used in earlier satellites, sent out a steady signal for tracking and temperature recording. One channel of the FM-AM telemeter was used to transmit variations in the missile's skin or package temperature.

A d.c. to d.c. static converter with excellent reliability and an efficiency of 82 per cent was used to convert the basic 18 volts to 135 and 270 volts. To limit filter components, a ripple frequency of 2,500 cps was used. The converter was transistorized, employing a common emitter circuit.

Since the satellite was expected to orbit for 20 days, it was decided that a nonrechargeable high-capacity chemical battery would be used rather than heavier and more costly silicon solar cells and nickel cadmium cells. A zinc-silver oxide battery was chosen because of a greater watt-hour per lb. capacity as compared to other batteries. A tapped battery was used utilizing 40 to 45 amp.-hour cells. An existing battery design was modified to permit a minimum weight. Cells of varying amp.-hour capacity, which would permit greater efficiency, were not used due to the short development period. The zinc-silver oxide cells were

Table 1

Components	Weight (lbs.)	Size (cu.in.)	Power Drain
Receiver	0.75	21	240/24 mw.*
Transmitter	2.5	101	41.5 watts
Recorder	3.25	99	1.4 watts record 1.35 watts playback
Control unit	0.75	37.5	0/3 watts
Tracking beacon	1.0	27	360 mw.**
Battery (cells)	21.0	175	
d.c. to d.c. converter	1.0	19	6.2 watts

* On 1/4 sec., off $2^1/_2$ sec., in stand-by operation. Continuous operation during record or retransmit operation.
** Continuous operation.

housed in a sealed container and thus were kept under pressure. Pressure was created by the hydrogen gas which was emitted by discharge. This had to be done as the liquid electrolyte in the cells would evaporate at a low temperature when placed in a vacuum.

The Atlas missile itself was used as the antenna, and was excited by slots located in the two pod covers. The standard slots for the Atlas missile were modified to serve for the communication frequencies. Further modification consisted of building new cavities and feeds. The resulting radiation pattern was similar to a long wire doublet antenna with associated nulls. Fades also were experienced at ground due to the 0.2 r.p.m. tumble rate of the satellite, but the system was designed with sufficient margin above threshold to compensate for most of these nulls.

Fig. 6 is a block diagram of the system in the satellite.

Ground Equipment

Since this article deals mainly with the satellite, the description of the ground equipment will be limited.

Each of the five communication sites contained two transmitters and receivers for communication, each capable of operating on two frequencies; two beacon receivers for tracking and temperature recording; and two control units.

One-kilowatt FM broadcast transmitters were modified for application and operation near 150 mc. per sec.

Standard 250-watt VHF transmitters were modified and used for stand-by.

FM fixed-frequency communication receivers were modified for operation at 132 mc. per sec. A fade filter was used in conjunction with the receiver.

(*Continued on page 74*)

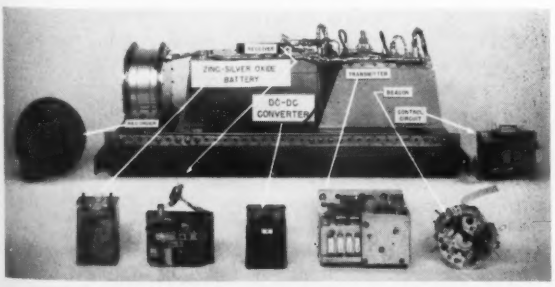


Fig. 5. Satellite equipment (components, overall front view).

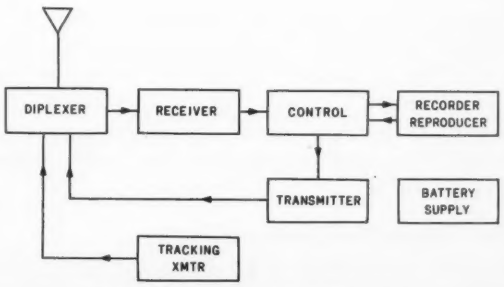


Fig. 6. Block diagram of satellite system.

"Weight comparisons of the possible combinations of L/D, mission, and type of cooling are a prominent part of the total configuration investigation results since, other factors being equal, lightest weight is the criterion of excellence."

Parametric Weight Study of a Manned Space Entry Vehicle

Onys A. Kelley, Jr., MIAS

Vought Astronautics, Division of Chance Vought Aircraft, Incorporated

THIS PAPER describes a manned space entry vehicle weight study which is an integral part of a comprehensive configuration investigation conducted by Vought Astronautics. The purpose of this study is to show weight comparison or trend data between different vehicles and heat-protection schemes. Both lifting and ballistic-type entry vehicles are investigated for satellite and circumlunar missions. The structural cooling methods studied are radiation, ablation, and a combination of radiation plus ablation. The method or approach used for this study is presented here in detail with sample calculations included.

The entry vehicles studied are based on the *modular concept* developed by Vought Astronautics. Under this concept, the entry vehicles are designed to be used in conjunction with a separable space laboratory or lunar mission module while performing a three-man, 14-day satellite mission or three-man, $7^1/_2$-day circumlunar mission. In this manner, the entry vehicles are sized for essentially "once around" conditions, and all mission equipment and systems not required for the entry itself are carried in the separable, nonreturnable module. The space laboratory or lunar mission module is outside the scope of this paper.

Lifting Vehicle Configurations

A family of modified half-cone lifting bodies for use as atmospheric entry vehicles is considered in this

Symbols

S	= wing area, ft.^{2} = projected area on a horizontal plane parallel to the cone axis of the vehicle (excluding control surfaces)
T_r	= reference temperature, °F. = radiation equilibrium temperature at the reference point on the bottom surface of a vehicle one foot back from the point of tangency of the bottom centerline and the nose
A_w	= total wetted area, ft.^{2} = total vehicle external area including base area and wetted area of control surfaces (control surface wetted area = 2 times projected area)
A_w/S	= shape factor = wetted area/wing area
W	= vehicle gross weight, lbs.
W_{avg}	= unit average structural weight, lbs./ft.^{2}
W_{ins}	= unit weight of insulation, lbs./ft.^{2}
W_{ext}	= unit external structural weight, lbs./ft.^{2} = unit external panel weight times 1.7
W_{int}	= unit internal structural weight, lbs./ft.^{2}, of vehicle wetted area
W_{abl}	= unit weight of ablation material, lbs./ft.^{2}
V	= velocity, ft./sec.
q	= heating rate, B.t.u./ft.^{2}-sec.
h_{eff}	= effective heat of ablation, B.t.u./lb.
contents weight	= gross weight minus structural weight
L/D	= lift drag ratio (dimensionless)
W/S	= wing loading, lbs./ft.^{2}
A	= projected frontal area, ft.^{2}
C_L	= lift coefficient (dimensionless)
C_D	= drag coefficient (dimensionless)
$(W/A)/C_D$	= ballistic parameter, lbs./ft.^{2}

study. The hypersonic maximum lift-drag ratio $(L/D)_{max}$ of these shapes can vary from close to zero to about 2.5 maximum, depending on the wedge or semi-cone angle and amount of nose and leading-edge bluntness. The basic shapes can be considered as either flat-bottomed or round-bottomed vehicles. A given half-cone body flying curved side down has somewhat less L/D than when flying flat surface down. The angle of attack of the bottom centerline is equal to the semi-cone angle in both cases.

Specific lifting vehicle configurations with L/D values of 0.5, 1.0, and 2.0 are selected for study, as shown by Fig. 1. Two $L/D = 0.5$ configurations are investigated, one a flat-bottomed vehicle and the other a round-bottomed vehicle with somewhat reduced semi-cone angle. In all cases, wing area S is taken to be the projected area on a horizontal plane parallel to the cone axis. Control surfaces, with projected area equal to approximately 20 per cent of the wing area, extend aft of the basic contours of the vehicle.

Vehicle Construction

Fig. 2 shows the typical structural arrangement of the family of entry vehicles. Construction of the vehicles employs a cool internal structure carrying primary loads and hot external skin panels carrying only local air loads. This allows the external panels to be designed to expand freely in order to avoid severe thermal stresses. The cylindrical pressure capsule provides the stiff and efficient primary load-carrying structure, and the external skins are supported from it by either trusses or corrugated webs.

The skin support structure is segmented to minimize the effect of thermal gradient between internal and external structure. The temperature of the skin support structure is limited to 1,600°F. by the use of insulation applied to the skin panels. Structural temperature of the pressure capsule is maintained at 200°F. by water wicking (evaporative cooling). Water wicking is excluded from the structural weight and listed as part of the environmental system.

The pressure capsule is of sandwich or composite, titanium or steel, monocoque construction. Metal external panels are of composite design (corrugated inner skin, flat outer skin, minimum gage 0.010 in.), and the graphite panels are assumed to be milled with integral stiffeners. The skin support structure is constructed of nickel alloy.

Mr. Kelley attended the University of Texas, majoring in mechanical engineering. His career in weight engineering began at Boeing (Wichita) in 1942 where his experience included weight research, preliminary design weight estimation, and the position of Project Weight Control Engineer on the XL-15 and B47 programs. Mr. Kelley joined Chance Vought in 1951 as a Project Weight Control Engineer and served in that capacity on the F7U-3 and F8U-3 programs. In 1957 he was assigned to the Advanced Aircraft Section, Weights Group, as an Engineering Specialist with supervisory responsibilities. In his present position, he is in charge of all weight control effort in the Vought Astronautics Division. Mr. Kelley is a senior member of the Society of Aeronautical Weight Engineers and a member of the IAS.

Materials

High-temperature materials are required for the radiation-cooled structure. Materials considered are nickel alloys, graphite, and the refractory metals—columbium, molybdenum, tungsten, and tantalum. Tungsten and tantalum are inferior to columbium and molybdenum alloys on a strength-weight basis and are not used in this study. A tantalum alloy containing 10 per cent tungsten has been developed recently, however, which shows attractive properties on a strength-weight basis.

Use of these materials requires an oxidation-protection coating. However, there is no known coating usable at temperatures greater than about 2,800°F. Therefore, structural weights for portions of any vehicle above this temperature are based on the assumption that the materials can be protected.

Test data on allowable stresses used for these exotic materials are based on average values. These are shown in Figs. 3 and 4. Recrystallized molybdenum values are shown since it is expected that molybdenum would be used above the recrystallization temperature. Columbium allowables are based on material in the as-received condition since it is expected that columbium would be used below its recrystallization temperature.

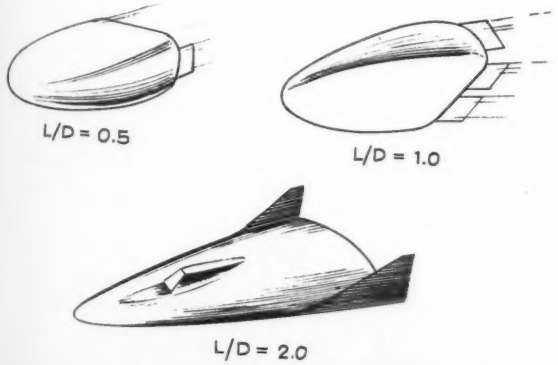


Fig. 1. Lifting vehicle configurations.

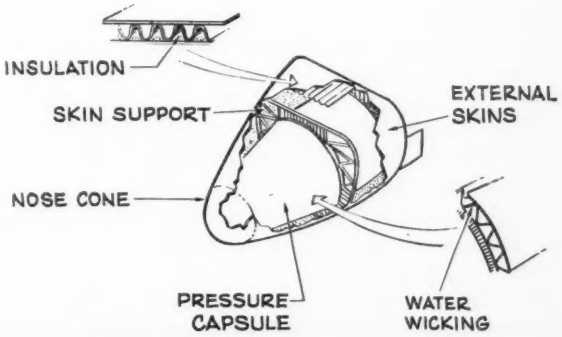


Fig. 2. Structural arrangement; $L/D = 0.5$ entry vehicle.

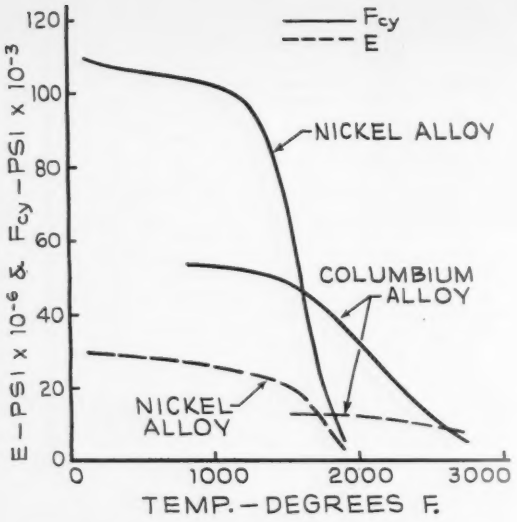


Fig. 3. Nickel alloy and columbium alloy allowables.

General Approach to Structural Weight Estimation

For convenience and ease of scaling, the structural weights are expressed as an average unit weight (pounds per square foot) based on the total wetted area of a vehicle including control surface wetted area. Structural unit weights are plotted against peak reference temperature. Reference temperature is defined as the radiation equilibrium temperature at the reference point on the bottom surface of a vehicle one foot back from the point of tangency of the bottom centerline and the nose.

There are no individual loads for the multitude of vehicles that must be analyzed; thus a scheme based on both analysis and judgment is used to make parametric estimates of structural weight. Structural weight is considered to be made up of four parts—internal weight, insulation, external weight, and ablation material weight.

Internal Structural Weight

The governing load conditions for internal structure occur during boost at 25,000 to 40,000 ft. where wind shear and gust loads are maximum and longitudinal accelerations are approximately 2.0*g*. Though some portions may be designed by high longitudinal *g* during entry or booster burnout and other portions by the requirements of local attachments, etc., internal structural weight is not fundamentally proportional to longitudinal *g*. This permits the familiar variation of primary structural unit weight with the product of gross weight times longitudinal load factor to be omitted, resulting in a considerable simplification of the weight estimation problem.

Since internal weight is made independent of external temperature through the use of insulation and water wicking, a constant internal structural weight of 1.4 lb. per sq.ft. of vehicle wetted area is used. This value is based on detailed analysis of a few specific vehicle layouts. Wetted area is total vehicle external area including base area and wetted area of control surfaces. Using total wetted area in this manner makes internal structural weight proportional to the size of the vehicle.

Insulation

Insulation to limit skin support structure temperature to 1,600°F. is applied over the inner surface of the skin panels. Insulation weight is based on "Q-Felt," a quartz fiber material with a temperature limit of about 3,000°F. Requirements above this temperature assume that an insulation material could be developed with properties similar to Q-Felt; however, such requirements are beyond the present practical structural material limits. Insulation weight (Fig. 5) depends on the maximum panel temperature, the limiting internal temperature, and the time at temperature. The increase in weight as L/D increases reflects the effect of time at temperature.

External Panel Weight

External panel designs are based on a normal pressure loading, $P = 2.6$ psi ultimate on a 24-in. span. The designs have been checked for resistance to panel flutter. For a given material, the panel weight is obtained for a temperature at which that particular material is most efficient. The weight for other temperatures is then varied as a function of $\sqrt{E\ Fcy}$. Graphite design is based on MC/I, with Ftu as the limiting stress. The weight variation with temperature for graphite is a function of $\sqrt{Ftu}$.

Plots of unit panel weight vs. panel temperature were computed for four materials (Fig. 6). These unit weights must be multiplied by a factor of 1.7 to account for the penalty portion of the vehicle external weight. The factor provides for such things as panel edge

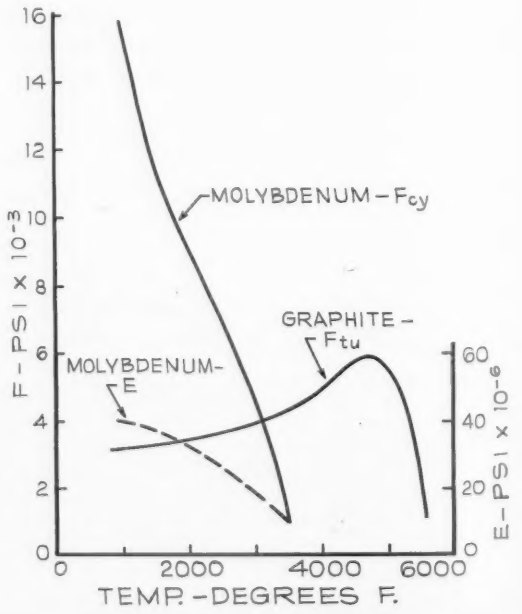


Fig. 4. Molybdenum and graphite allowables.

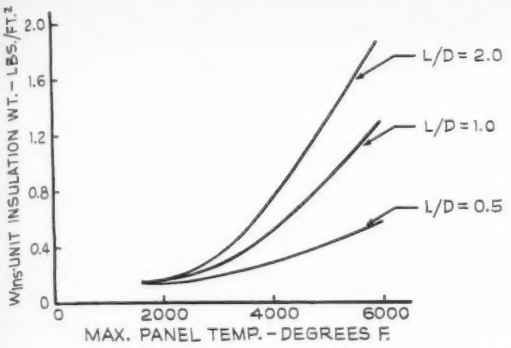


Fig. 5. Insulation required to limit skin support structure to 1,600°F. maximum.

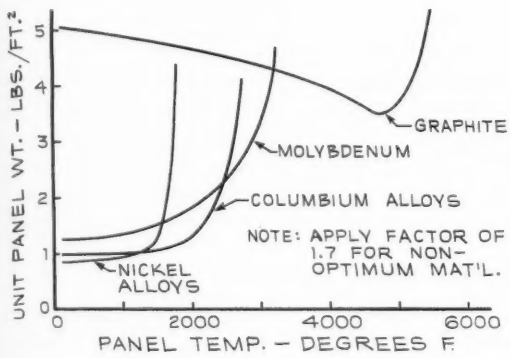


Fig. 6. Unit panel weight vs. temperature.

support, hardware, hatches, cutouts, fittings, etc., and is based on layout analysis of specific vehicles.

Vehicle Layouts

Layouts are made of vehicles having the correct geometric relationships for each L/D. These may be of arbitrary size in the beginning but are usually drawn according to some pre-established ground rule. In this study, minimum vehicle size is basically set by the dimensions of the three-man crew, and this results in a vehicle which is not volume limited with respect to equipment. From these drawings, vehicle wing area, total wetted area, and total volume are calculated. The relationship of wetted area divided by wing area is termed "shape factor" and is used for sizing other vehicles of the same L/D—that is, for a given L/D, the shape factor remains constant as wing area is varied.

Trajectories and Aerodynamic Heating

For atmospheric entry from circular satellite speed, equilibrium glide paths—that is, lines of constant $(W/S)/C_L$—are followed.

A returning vehicle approaches the earth from the moon at approximately escape speed. The basic problem is then to determine the best way to reduce speed from escape to satellite from the standpoint of vehicle temperature, total heat, and maximum deceleration, all of which are reflected in the vehicle weight. For purposes of this paper, a semiballistic entry is used. The perigee of the ballistic approach path is placed within the atmosphere at some velocity above circular satellite speed. Negative lift is then employed to maintain constant altitude until speed decreases to satellite speed. As speed decreases below circular satellite speed, positive lift is gradually applied until the design $(W/S)/C_L$ line is reached.

Other types of trajectories considered for lunar return were:

(1) *Pure ballistic*—in which the approach perigee is placed deeper within the atmosphere than in the semiballistic entry and occurs at satellite speed because of the increased drag.

(2) *Drag device*—a variation of the semiballistic entry attained by adding a drag brake to the basic vehicle to increase the perigee altitude, decrease the perigee speed, and therefore decrease maximum temperature.

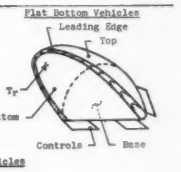
(3) *Pull-up maneuver*—consisting of a relatively steep entry which uses positive or upward lift to decrease the flight path angle. When the speed after the pull-up is above circular satellite speed, a constant altitude trajectory is followed as in the semiballistic entry. This entry is characterized by a short pulse of high temperature and deceleration.

For each particular vehicle shape and trajectory, time histories of reference temperature and heating rate at the reference point are calculated for various wing

Table 1. Unit Average Structural Weight Calculation
Weighted Average Method

Flat Bottom Vehicles

Section	L/D = 0.5 T^4/P	L/D = 0.5 A/A_w	L/D = 1.0 T^4/P	L/D = 1.0 A/A_w	L/D = 2.0 T^4/P	L/D = 2.0 A/A_w
Lead Edge	T_r + 500	.11	T_r	.11	T_r + 500	.15
Top	.62 T_r	.41	.63 T_r	.33	.63 T_r	.42
Bottom	.90 T_r	.13	.93 T_r	.21	.93 T_r	.24
Base	.50 T_r	.23	.50 T_r	.20	.50 T_r	.13
Controls	.75 T_r	.12	.75 T_r	.15	.75 T_r	.06



Round Bottom Vehicles

Round Bottom Vehicle - L/D = 0.5 Section	T^4/P	A/A_w
Lead Edge	T_r + 1050	.04
Top & Control	.73 T_r	.38
Bottom-Fore	.94 T_r	.11
Bottom-Aft	.79 T_r	.22
Base	.50 T_r	.25

$$W_{avg} = \frac{A_1}{A_w}\left(W_{ins} + W_{ext}\right)_1 + \frac{A_2}{A_w}\left(W_{ins} + W_{ext}\right)_2 \cdots + \frac{A_n}{A_w}\left(W_{ins} + W_{ext}\right)_n + W_{int}$$

Lbs./Ft.² where subscripts denote sections of the vehicle.

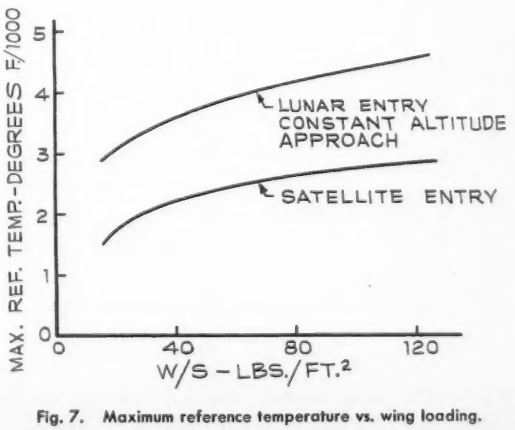


Fig. 7. Maximum reference temperature vs. wing loading.

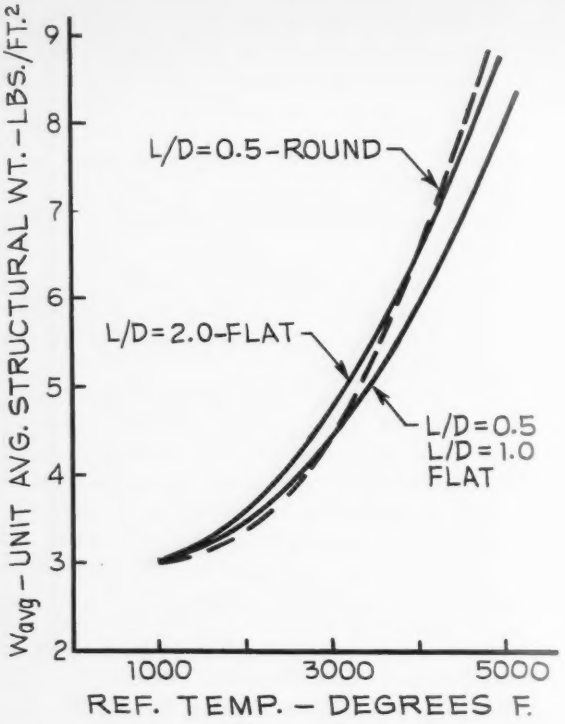


Fig. 8. Unit average structural weight; radiation-cooled vehicles, satellite and lunar.

loadings. Maximum reference temperature is then plotted vs. wing loading for both satellite and lunar entry (Fig. 7). It should be noted that for the two particular trajectories considered, reference temperature for a given wing loading is the same for all L/D ratios. Fig. 7 therefore requires only two curves—one for satellite entry using equilibrium glide path and the other for lunar return entry with constant altitude approach.

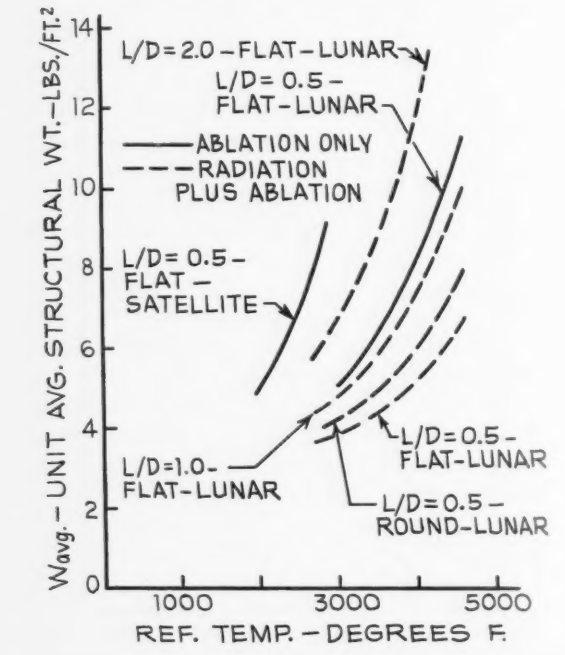


Fig. 9. Unit average structural weight; radiation plus ablation and ablation only cooled vehicles.

Unit Average Structural Weight

Radiation Cooling

The wetted area of each vehicle is divided into five sections having fairly uniform temperatures. The average temperature of each section is expressed in terms of the reference temperature T_r by using the various curves available for estimating radiation equilibrium temperatures on spheres, cylinders, and flat plates. For arbitrary values of reference temperature, it is now possible to tabulate the temperature of each area and the ratio of this area to the total wetted area of the vehicle, as shown by Table 1. Using Figs. 5 and 6 and Table 1, we now compute the unit average structural weight for a particular vehicle at an arbitrary reference temperature. By repeating this process for a series of reference temperatures and for each L/D, we obtain unit average structural weight vs. reference temperature for radiation-cooled vehicles (Fig. 8).

Ablation Cooling

In order to limit the external skin temperature of a vehicle, an ablative coating may be applied. Ablators range from low-temperature plastic materials to high-temperature glassy materials. The heating rates and substructure temperature limits are such that low-temperature plastic ablators are most suitable for this vehicle. Teflon has been used as the ablating material.

From the time histories of heating rate and radiation equilibrium temperature at the reference point, heating rate curves for other sections of the vehicle are computed by

$$q = (T/T_r)^4 q \text{ ref.}$$

where T is in °R., and q is in B.t.u./ft.²-sec.

The effective heat of ablation, h_{eff}, is then calculated for the trajectory. The effective heat of ablation is primarily a function of the properties of the material, the velocity of the vehicle, and the quality of the boundary layer (laminar or turbulent). A simplified approximate h_{eff} equation for Teflon using turbulent flow (everywhere except leading edges) is as follows:

$$h_{\text{eff}} = 750 + 2.74 \times 10^{-6} V^2 = \text{B.t.u./lb.}$$

where V is in ft./sec.

The equation used for laminar flow on leading edges is

$$h_{\text{eff}} = 750 + 8.77 \times 10^{-6}\ V^2$$

The unit ablation weight for each section of the vehicle is found by dividing the q curve by the h_{eff} curve and integrating over the proper time span:

$$W_{\text{abl}} = \int_{t_1}^{t_2} \frac{q}{h_{\text{eff}}}\, dt = \frac{\text{lbs.}}{\text{ft.}^2}$$

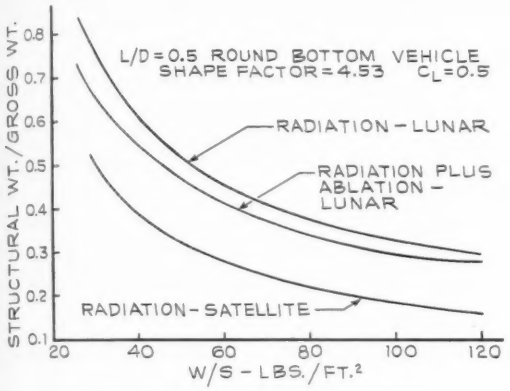


Fig. 10. Structural weight ratio vs. wing loading.

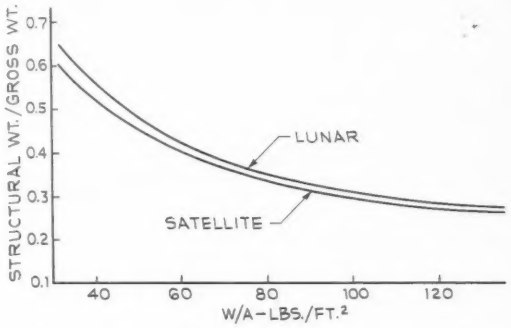


Fig. 12. Structural weight ratio vs. W/A; ballistic vehicles.

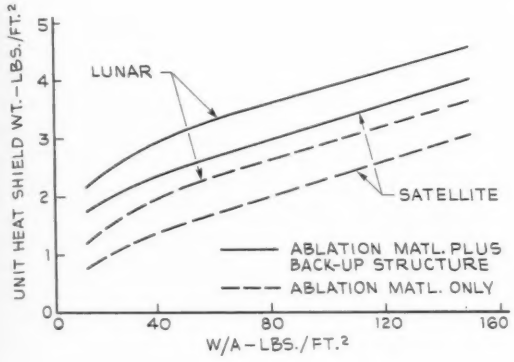


Fig. 11. Unit heat shield weight; ballistic vehicles.

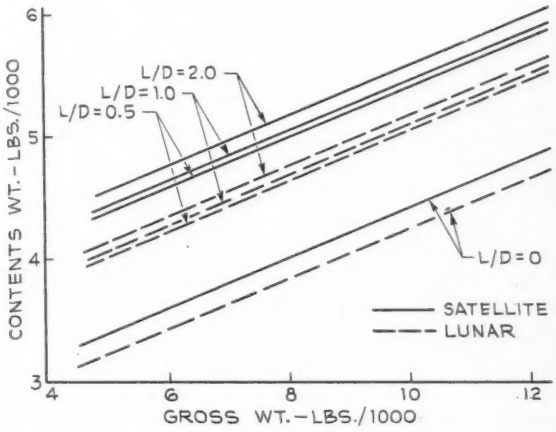


Fig. 13. Contents weight vs. gross weight; three-man entry vehicles.

Table 2. Structural Weight Ratio Determination

Sample Calculation Sheet

L/D = 0.5, Round Bottom, Radiation Cooled Satellite Vehicle

Constants: Wing Area = 81 Sq. Ft.
Shape Factor = 4.53
Wetted Area = 367 Sq. Ft.
Volume = 441 Cu. Ft.

W/S	Gross Wt. Pounds	Ref. T °F	Struct. Unit Wt. Lb./Sq. Ft.	Struct. Wt.-Lbs.	Struct. Wt. Ratio	Contents Wt. Ratio
30	2430	2050	3.40	1250	.514	.486
40	3240	2210	3.50	1286	.397	.603
50	4050	2330	3.63	1333	.329	.671
60	4860	2440	3.75	1378	.284	.716
70	5670	2520	3.83	1408	.248	.752
80	6480	2600	3.90	1432	.221	.779
90	7290	2660	4.00	1470	.202	.798
100	8100	2725	4.08	1500	.185	.815
110	8910	2790	4.20	1541	.173	.827
120	9720	2850	4.28	1570	.162	.838

Table 3. Contents Weight Breakdowns, Lbs.

Minimum-Sized Three-Man Vehicles

	Lifting L/D = 0.5		Ballistic L/D = 0	
	Satellite	Lunar	Satellite	Lunar
Environment	410	410	300	300
Water Wicking	290	310	0	0
Crew	540	540	540	540
Controls	560	460	250	250
Instrumentation	220	220	220	220
Displays & Instruments	160	190	70	100
Guidance & Navigation	270	270	90	90
Communications	190	190	190	190
Electrical Power Supply	290	320	270	290
Furnishings & Misc.	340	340	340	340
Propulsion-Landing Etc.	1350	1050	1150	900
TOTAL CONTENTS WEIGHT	4620	4300	3420	3220
VEHICLE GROSS WEIGHT	(5940)	(6370)	(5100)	(4980)

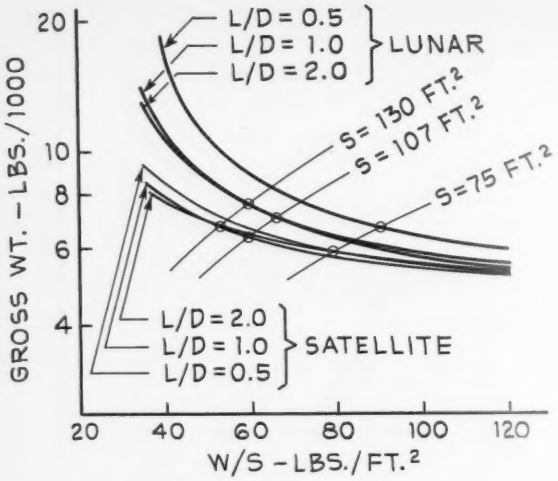


Fig. 14. Gross weight vs. wing loading; radiation cooling only. (Intersections represent minimum-sized vehicles.)

where t_1 is the time at which ablation begins, and t_2 is the time ablation ends either by having the temperature drop to a point where ablation cannot continue or by choice through limiting the amount of ablation material applied. For convenience, the above integration may be performed graphically.

The unit average ablation weight for the entire vehicle is found by the weighted average method analogous to Table 1 for the radiation-cooled structure. Total unit average weight is the sum of the unit average weights of the radiation-cooled structure and the ablation material. This is plotted against the radiation equilibrium temperature at the reference point (Fig. 9).

The h_{eff} equations show ablation material to be more efficient at the higher velocities. The ablation approach is more efficient for short-time applications. Heating rates for a given reference temperature are the same at all L/D's in the range evaluated, but the entry times—and hence the total heat—increase directly with L/D. Therefore, ablation material weight increases as a function of L/D.

Unit Average Structural Weight Curves

The unit average structural weight curves (Figs. 8 and 9) fall into three categories:

(1) Radiation cooled (Fig. 8): These are applicable to both satellite and lunar missions.

(2) Ablation only (Fig. 9): The curve labeled "satellite ablation only" is for a vehicle using ablation for the entire satellite entry trajectory. The curve labeled "lunar ablation only" is for the same vehicle extended to include the lunar mission.

(3) Radiation plus ablation cooled (Fig. 9): The curves labeled "lunar" are for radiation-cooled satellite vehicles extended to include the lunar mission by adding ablation material. Just enough ablation material is added to the vehicle skin so that the external skin temperatures on the lunar entry do not exceed those on the satellite entry.

It should be noted that the curves of Figs. 8 and 9 do not indicate relative efficiency between vehicles of different L/D since vehicle gross weight is a function of the minimum wetted area possible with the payload required to do a particular mission.

It should also be pointed out that the unit weight of ablation material required to extend a satellite vehicle to the lunar mission is not the difference between the ablation curve and the radiation curve at a particular temperature since satellite vehicles and lunar vehicles are plotted against different reference temperatures (Fig. 7).

Structural Weight Ratio Determination—Lifting Vehicles

Table 2 shows sample calculations for a vehicle structural weight ratio curve. Using a constant wing area for a given L/D (based on the designer's layout), we establish vehicle gross weights for an arbitrary family of wing loading values. From the applicable curve of Fig. 7, a unique reference temperature is assigned to each value of W/S. Total structural weight for each W/S value is then calculated using constant wetted area and the applicable curve of unit average structural weight from Fig. 8. Structural weight ratio is then obtained for each value of W/S by dividing total structural weight by gross weight. The resulting plot of structural weight ratio vs. W/S (Fig. 10) is applicable to vehicles of any wing area having the designated shape factor, L/D, and C_L value. Structural weight ratio plots similar to Fig. 10 are calculated for each L/D of the series.

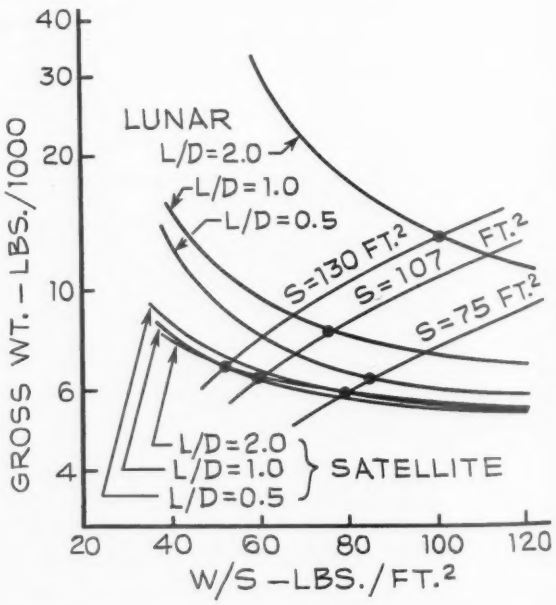


Fig. 15. Gross weight vs. wing loading; lunar vehicles—radiation plus ablation, satellite vehicles—radiation. (Intersections represent minimum-sized vehicles.)

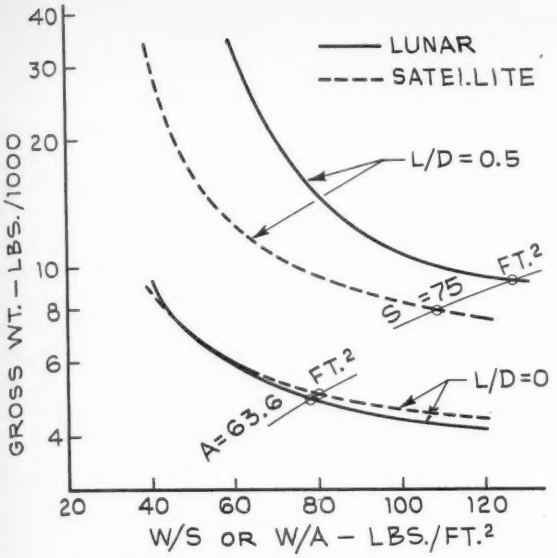


Fig. 16. Gross weight vs. wing loading; ablation cooling only. (Intersections represent minimum-sized vehicles.)

Unit Heat Shield Weight—Ballistic Vehicles

Construction of the ballistic vehicles is assumed to be geometrically similar to the Project Mercury configuration. Ablation is the primary method of structural cooling. Teflon is used for the heat shield with a load-carrying beryllium back-up structure. Radiation cooling is used on the afterbody.

Trajectory studies provide time history plots of heating rates and radiation equilibrium temperatures vs. $(W/A)/C_D$ for analysis of the amount of ablation material required for satellite and lunar missions. Time histories of velocity and altitude are also obtained from which plots of maximum pressure vs. $(W/A)/C_D$ are made. These are used to analyze the back-up structure which is designed for hoop compression. A minimum beryllium thickness of 0.10 in. is assumed which proves satisfactory for the range of W/A investigated. Since C_D is a constant, unit weights of required ablation material—with and without the back-up structure—are plotted as a function of W/A (Fig. 11).

Structural Weight Ratio Determination—Ballistic Vehicles

Structural weight ratios for ballistic vehicles, both satellite and lunar, are obtained by a process similar to the one used in Table 2 for lifting vehicles. Based on the constant minimum frontal area required for the three-man crew and the same C_D used in the trajectory studies, vehicle gross weights are set up for an arbitrary family of W/A values. At this point, the unit average structural weight concept used for the lifting vehicles is abandoned, and primary structural gages and weights are calculated for each chosen value of W/A by scaling from Vought's proposal for Project Mercury. Weight penalties for nonoptimum factors are added, plus the weight of heat shield and back-up structure from Fig. 11, to obtain total structural weight. Values of structural weight ratio are then calculated and plotted as a function of W/A (Fig. 12).

Contents Weight

For purposes of this study, contents weight includes all subsystems, equipment, and crew; in other words, contents weight equals gross weight minus structural weight. Fig. 13 shows the plots of contents weight vs. gross weight used for satellite and lunar vehicles, both lifting and ballistic. The straight-line variations shown are considered adequate for a parametric study of this type.

The lines shown actually consist of a constant portion representing system and equipment items which are dependent only on mission (independent of gross

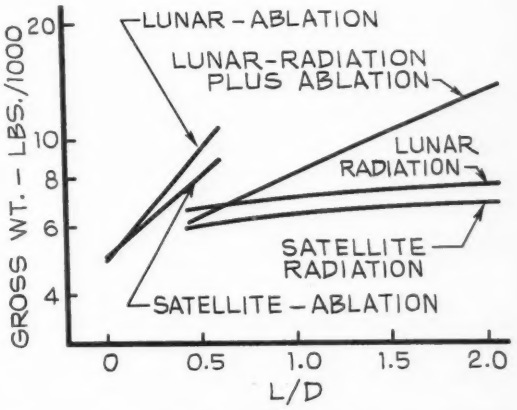


Fig. 17. Gross weight vs. L/D; three-man minimum-sized vehicles, satellite and lunar.

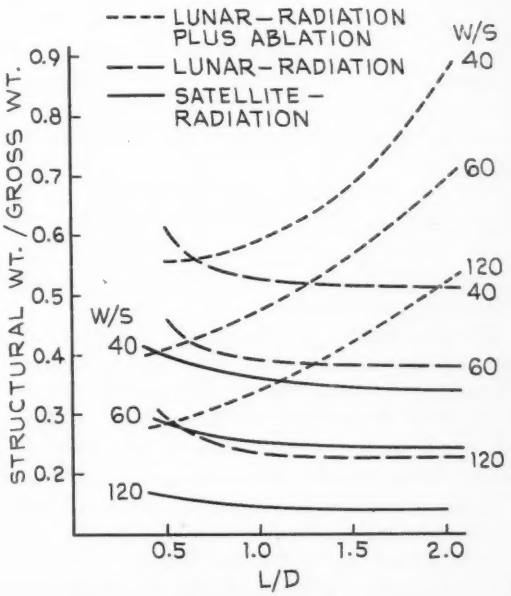


Fig. 18. Structural weight ratio vs. L/D.

Table 4. Vehicle Gross Weight Iteration
Sample Calculation Sheet

L/D = 0.5, Round Bottom, Radiation Cooled Satellite Vehicle

Constant Shape Factor = 4.53

Variables: Wing Area

Wetted Area

Contents Weight

W/S	*Contents Wt. Ratio	First Approximation Contents Wt. Pounds	First Approximation Gross Wt. Pounds	Final Iteration Contents Wt. Pounds	Final Iteration Gross Wt. Pounds
40	.603	4960	8230	5130	8500
60	.716	4720	6580	4740	6620
80	.779	4620	5930	4600	5900
100	.815	4560	5600	4540	5670
120	.838	4520	5380	4480	5350

* 1 - Structural Weight Ratio

Table 5. Summary—Specific Vehicles

L/D	Shape of Bottom: Round	Shape of Bottom: Flat	Mission: Sat.	Mission: Lun.	Type of Cooling: Rad.	Type of Cooling: Abl.	Type of Cooling: Rad.Abl.	Min.Sw-Sa.Pt.	Wt. of Contents-Pounds	W/S	Design Ref.Temp.-°F	Struct. Wt.Ratio	Wt. of Vehicle-Pounds
0			x		x			*63.6	3420	80.2	2700**	.33	5100
0				x		x		*63.6	3220	78.3	4000**	.35	4980
.5	x		x		x			75	4620	79.3	2650	.22	5940
.5	x			x			x	75	4300	84.9	4220	.33	6370
.5	x			x	x			75	4390	90.0	4280	.35	6750
.5		x	x			x		75	5030	107.3	2800	.38	8050
.5		x		x		x		75	4940	126.7	4600	.48	9500
1.0		x	x		x			107	4770	59.6	2460	.25	6380
1.0		x		x	x			107	4520	66.4	4000	.37	7110
1.0		x		x			x	107	4710	75.9	4110	.42	8120
2.0		x	x			x		130	4970	52.2	2380	.27	6780
2.0		x		x	x			130	4700	58.8	3900	.39	7640
2.0		x		x			x	130	5920	104.3	4400	.56	13300

*Projected Frontal Area
**Stagnation Temperature

weight) plus the items which are assumed to vary directly with gross weight. This latter category includes the retro system, the vertical rocket-type landing system, and the control systems, both reaction and aerodynamic types.

The lifting vehicle's contents weight increase with L/D for a given gross weight represents essentially increases in environmental system, electrical power, and reaction control propellant required as entry time increases. These curves may not be used directly to compare contents weights for various L/D ratios, however, because minimum-sized vehicle gross weights are not the same for all values of L/D, as will be demonstrated.

The reduced contents weight for ballistic vehicles—as compared to lifting—reflects primarily the deletion of water wicking and aerodynamic controls and the reduction of guidance, instrumentation, and electrical power requirements.

Contents weight used for a given gross weight is less for the lunar mission than for the satellite mission, primarily because no retro propellant is required in the lunar case. Propellant for course correction when returning to the earth from the moon is carried in the lunar mission module rather than in the entry vehicle.

Escape rockets for both satellite and lunar missions are assumed to be jettisoned at booster burnout and are excluded from vehicle contents weight.

Table 3 shows contents weight breakdowns which substantiate one point each on the $L/D = 0.5$ and $L/D = 0$ satellite and lunar contents weight curves of Fig. 13.

Vehicle Gross Weight vs. Wing Loading

Table 4 shows sample calculations for vehicle gross weight variation with wing loading. This calculation is repeated for each L/D, mission, and type of cooling. The actual calculation for each value of W/S (or W/A in the case of ballistic vehicles) is an iterative process involving use of the applicable structural weight ratio curve and the applicable contents weight curve from Fig. 13. An assumed contents weight is divided by the contents weight ratio (1-structural weight ratio) to obtain a tentative gross weight. The assumed contents weight is then corrected (using Fig. 13), and the process is repeated until compatible values of contents weight and gross weight are obtained. Figs. 14, 15, and 16 show the resulting curves of vehicle gross weight vs. W/S or W/A for all the combinations of L/D, mission, and type of cooling considered in this study.

Specific Vehicle Gross Weight—Ground Rule Selection

The form in which the results of the parametric study are expressed (Figs. 14, 15, and 16) is well suited to a specific solution for any set of ground rules involving mission, L/D, W/S, and type of structural cooling. The following solution derives specific vehicle gross weights based on a minimum-sized vehicle containing a crew of three. Other assumptions as to crew and/or size could be made, such as a maximum limiting temperature for design of radiation-cooled vehicles.

For the minimum-sized vehicle solution, lines of constant minimum wing area (or frontal area in the ballistic case) for each L/D are superimposed on the gross weight vs. wing loading lines of Figs. 14, 15, and 16. The intersection of each constant minimum wing area line with the gross weight lines for the corresponding L/D defines a pair of specific vehicles, one satellite and the other lunar.

It should be noted that, in each case, the lunar vehicle thus defined is a growth version of the satellite vehicle having the same wing area. In Fig. 14, the radiation-cooled lunar vehicles may be obtained by changing the outer skin material and insulation of the satellite vehicles while retaining the same internal structural design. In Fig. 15, the satellite vehicles shown are radiation cooled and are the same points shown in Fig. 14. The lunar vehicles are obtained simply by adding ablation material. In Fig. 16, lunar vehicles cooled by ablation only may be obtained by increasing the amount of ablation material on the satellite vehicles.

Final Results—Minimum-Sized Vehicles Gross Weight vs. L/D

In Fig. 17, the specific minimum-sized vehicle weights defined by Figs. 14, 15, and 16 are plotted against L/D ratio. Fig. 17 shows the variation of vehicle gross weight with L/D for each mission and method of structural cooling studied. It represents

the condensed result of the manned space vehicle study in terms of weight optimization.

Fig. 17 shows that the weight of minimum-sized three-man vehicles increases with increasing L/D throughout the range studied and for all missions and types of structural cooling studied. The radiation-cooled satellite vehicles are in the 6,000- to 7,000-lb. gross weight range; radiation-cooled lunar vehicles are in the 7,000- to 8,000-lb. range. The pure ablation-cooled vehicles are the lightest studied (5,000 lbs.) at $L/D = 0$ for either mission, but at $L/D = 0.5$ they weigh 8,000 and 9,500 lbs. for the satellite and lunar missions, respectively, and are heavier than vehicles cooled by the other methods. Table 5 presents in tabular form the characteristics of the 13 specific vehicles defined by this study.

Analysis of Results

Certain additional cross-plots of information vs. L/D are of benefit in interpreting the results of this study. Fig. 18 shows structural weight ratio vs. L/D for lines of constant W/S. Satellite and lunar missions with radiation cooling and the lunar mission with radiation plus ablation cooling are shown.

It will be noted in Fig. 18 that structural weight ratio for the radiation-cooled vehicles decreases as L/D ratio increases. This is due to the reduction of shape factor and hence the reduction in wetted area for a given wing loading as L/D increases. Fig. 17 shows that gross weight increases with increasing L/D, however, because the overriding factor is the increase in minimum wing area required to house the three-man crew as shape factor and volume decrease.

On the radiation plus ablation curves of Fig. 18, the effect of increasing ablation material weight with increasing L/D is quite apparent and overrides the shape factor effect.

Figs. 19, 20, and 21 are plots of vehicle gross weight vs. L/D and are cross-plots of the information shown in Figs. 14 and 15. The minimum-sized curves in Figs. 19, 20, and 21 are the same curves shown as final results in Fig. 17. The area below the minimum-sized curves represents vehicles which lack the required crew volume.

In Figs. 19 and 20—radiation-cooled satellite and lunar vehicles, respectively—the increase in gross weight as L/D decreases toward 0.5 is due to the effect of increasing shape factor and hence increasing structural weight ratio. The increase in gross weight as L/D increases toward 2.0 reflects the increase in contents weight with increasing L/D in a region where the structural weight ratio curves are relatively flat. Both of these effects at the extremes of the L/D range are amplified by an increase in the general level of structural weight ratio. The "bucket" in the curves is therefore more pronounced at the low wing loadings and for the lunar vehicles. The location of this "bucket" defines the optimum L/D ratio for minimum vehicle gross weight whenever a limiting wing loading

(*Continued on page 77*)

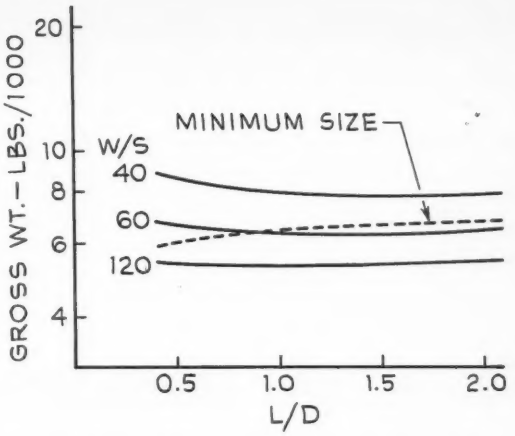


Fig. 19. Gross weight vs. L/D; satellite vehicles—radiation cooled.

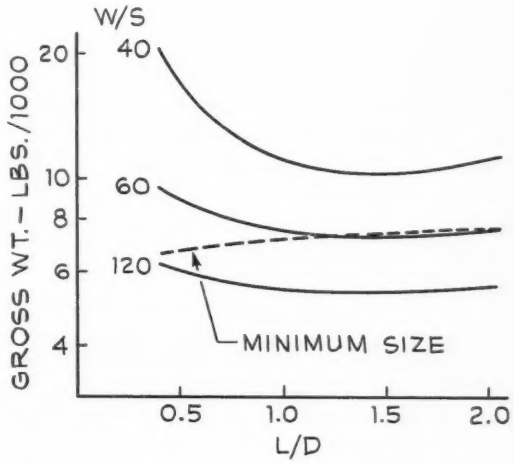


Fig. 20. Gross weight vs. L/D; lunar vehicles—radiation cooled.

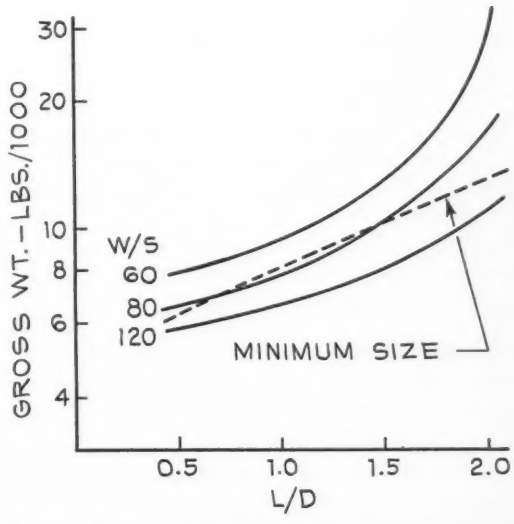


Fig. 21. Gross weight vs. L/D; lunar vehicles—radiation plus ablation cooled.

"Existing facilities do not provide the simulation capability required for full exploitation of man's capabilities in future space flight systems."

Space Flight Simulators—*Design Requirements and Concepts*

R. O. Lowrey, MIAS, *Lockheed Aircraft Corporation*

THE EFFICIENT UTILIZATION of man's capabilities in future space flight systems requires a capability to (1) define his specific task contribution to the mission, (2) select the overall environment to which he is to be subjected, (3) evaluate his performance of the specific tasks within the environment provided, and (4) train him in order to improve his performance.

The first two items must be accomplished in the early stages of system design and must, therefore, be based upon data which is on hand at the time. The critical and irrevocable nature of such decisions on flight-system performance demands that increasingly refined data be made available in this area. As a result of the divergence of the flight-system environment from man's natural environment and the complexity of space flight systems, the evaluation of man's performance and his training must receive greater attention in the future. These factors point toward an ever increasing role for space flight simulators.

Mr. Lowrey is a Group Engineer in Preliminary Design of the Georgia Division of Lockheed Aircraft Corp. He received a B.S. in Aeronautical Engineering from the Georgia Institute of Technology, and an M.S. in A.E. from the California Institute of Technology in 1943 and in 1949, respectively. He completed a one-year course of study at the Oak Ridge School of Reactor Technology in 1953. His background includes 7 years' experience in preliminary design during which time he has participated in studies and proposals of nuclear aircraft weapon systems, boost-glide vehicles, space vehicles, and space flight simulators. Mr. Lowrey is a member of the IAS and AAS.

Simulator Requirements

Man's experiences in space flight will be represented by the sum of the environmental factors which he perceives. The objective of space flight simulation is the representation of the total anticipated environment with sufficient realism to induce the same physiological and psychological responses as will occur in the true situation being represented.

Environmental Elements

The major elements which convey environmental situations to man are (1) an acceleration field, which is considered for convenience in three degrees of freedom of translation and three of rotation; (2) a gaseous environment, as represented by temperature, pressure, and composition; (3) a visual field; and (4) an aural field.

In his natural habitat, man is provided with combinations of these elements that are tolerable for many years. If any of these elements are altered from their natural values, however, man's ability to function normally is impaired.

The greater the variation from normal, the shorter the time period which can be endured, as shown by the representative curve of Fig. 1. Simulation of space flight situations then requires the representation of the time variation of the above environmental elements.

Environmental Situations

For the sake of convenience, consider space flights to be categorized as follows:

(1) Departure.
(2) Mid-course.
(3) Rendezvous.
(4) Landing (including atmospheric re-entry).
(5) Terminal mission operations.

Not all space flights will necessarily include each phase; however, these are sufficiently broad to cover most flight situations.

The objective is to consider each of these phases in terms of the characteristic environmental situations to be presented to man.

Departure—This phase will cover a relatively short interval of time, and will thus permit deviation from the normal values of the environmental elements if such is desirable from an overall design standpoint.

The prime characteristic of this phase is the high acceleration along the longitudinal axis of the vehicle as represented by Fig. 2. Secondary accelerations may occur in any of the six degrees of freedom.

The gaseous environment may be altered slightly from normal conditions in composition and pressure but not to an extent that will be perceived by the man under those conditions. During the penetration of the atmosphere, it may be desirable to accept a relatively high-temperature transient of short duration.

As a result of the high-axial acceleration, man will be relatively immobile. His visual environment will be limited to a narrow range in the vicinity of his fixed station. It is not likely that coordinated efforts will be dependent on visual reference to other crew members.

The external aural environment will initially approach an intolerable level. Since altering of this for the vehicle occupants incurs weight penalties, short-term tolerance values may be used.

Mid-Course—This phase is characterized by a long-time interval. It may constitute either the manning of a space station or interplanetary flight.

The zero-gravity state will be the representative acceleration phenomena. Intermittent operation of control devices may cause occasional accelerations of small magnitude in the six degrees of freedom.

As a result of the long period of time involved, the gaseous environment must be near optimum for man's continued useful performance. This may consist, however, of the optimum oxygen-partial pressure, plus a low-partial pressure of an inert gas to give a total pressure less than normal.

The visual environment will cover the total internal confines of the space vehicle. Activities will be on the basis of coordinated group effort. Work-rest cycles will be established without reference to the usual diurnal environment. Since the total environment is essentially contained within the vehicle, the vehicle size and facilities will be critical.

The audible environment will be that generated by the equipment and personnel within the vehicle.

Rendezvous—This phase represents the relatively short period during which time adjustment in trajectory is made to enter the desired orbit or position relative to the body being approached.

The acceleration field may vary from zero to moderate values of acceleration resulting from controlled impulses.

There will be little reason to deviate appreciably from the ideal gaseous environment except, possibly, in pressure and composition.

The visual environment will include visual reference to the body being approached as well as the internal aspects of the space vehicle. The elapsed time for this phase will be such that the volume provided and overall group activity will be of less consequence than during the mid-course phase.

The audible environment will again be derived totally from within the vehicle.

Landing—The time period for this phase will be relatively short.

The acceleration field will be highly dependent on the vehicle concept. If a blunt body re-entry into an atmosphere is performed, the axial acceleration field will be quite high. If a lift to drag ratio greater than one is used, the axial acceleration will be relatively low. Deceleration patterns representative of these re-entry techniques are shown by Fig. 2. In either case, secondary motions in all six degrees of freedom may occur.

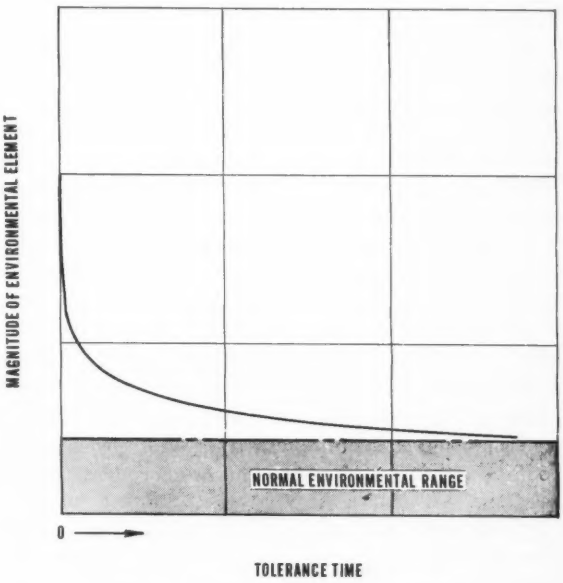


Fig. 1. Tolerance to environmental elements.

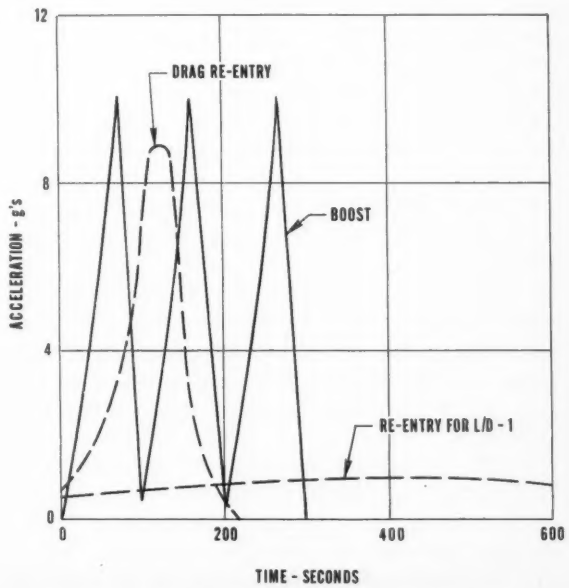


Fig. 2. Typical boost and re-entry acceleration patterns.

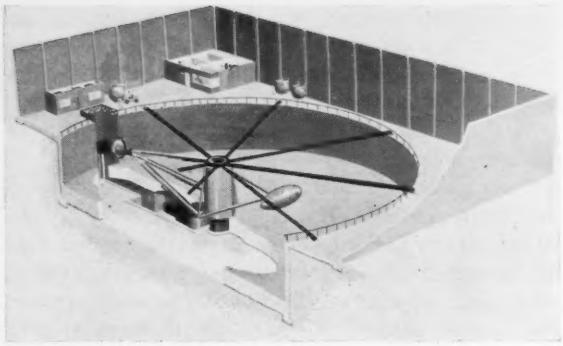


Fig. 3. Space flight acceleration simulator.

No significant compromise in the gaseous environment is likely. A slight transient in temperature may be utilized during re-entry.

The visual environment must include the body being approached and provide reference of relative position and velocity. Mobility will be limited during this period so that the individual station will represent the principal internal visual environment.

The audible environment will include wind noise, as well as internally generated noise.

Terminal Mission Operations—This phase provides a variety of alternatives. For purposes of this paper, the construction of a space station will be considered.

The active phase of space-station construction will likely encompass a period of time no greater than a standard work period.

The acceleration field will vary from zero to values resulting from control impulses and contact with other bodies. Accelerations will occur in all six degrees of freedom.

The gaseous environment may be compromised in pressure and composition, but not to an extent discernible by man. Temperature control should be near optimum.

The external visual environment will be composed of the relative position and motion of other bodies. The internal aspects of the space suit or vehicle will compose the internal visual environment.

The audible environment will be that generated within the vehicle or by contact with other bodies.

Synthesis of Requirements

Considering the diversity of situations to be simulated, it does not appear feasible or expedient to provide a single simulator to meet all of the conditions to be covered. By comparing the characteristics of each flight phase toward establishing the minimum, distinctly different devices necessary to provide a capability of simulating each phase separately, the following is concluded:

(1) The general character of the departure and landing phases are quite similar in requiring a sustained acceleration, and six degrees of freedom motion relative to a large essentially fixed body.

(2) The mid-course phase is unique in the extended period of time covered, the importance of group behavior, and the relatively secondary nature of accelerations and orientation.

(3) The terminal mission phase is unique in requiring undamped motion in six degrees of freedom of two or more bodies, which are capable of making contact with each other.

(4) The rendezvous phase is similar to the departure and landing phases, when a large body such as the moon or a planet is being approached. If a small body is being approached, the rendezvous is similar to the terminal mission phase.

From this, it is seen that by simulating three distinct types of environmental situations, the capability of simulating each of the five flight phases is afforded.

Simulator Concepts

Departure and Landing Phases

The most difficult aspect of this simulation is the representation of the desired accelerations. The only known means for producing the required sustained acceleration field is by use of a centrifugal device. The most refined device of this nature, currently in operation, is located at the Naval Air Development Center, Johnsville, Pa. In addition to the primary rotational motion, the Johnsville centrifuge provides two degrees of freedom of rotation of the test capsule. In a pioneering application of centrifuges to dynamic flight simulation, it has been used successfully in the investigation of the X-15 flight problems.

A centrifugal device with the capability of providing six degrees of freedom motion is required, however, for more accurate representation of free flight motions. The centrifuge shown by Fig. 3 provides such a capability. This design has been investigated within the Advanced Design organization of the Georgia Division of Lockheed.

The simulator consists of an experimental capsule, the mechanism for producing the sustained radial acceleration field and the six degrees of freedom of movement, and the control and computer system.

The test subject is housed within the 8-ft. diameter spherical capsule. The simulator provides the following acceleration capability for the capsule and test subject.

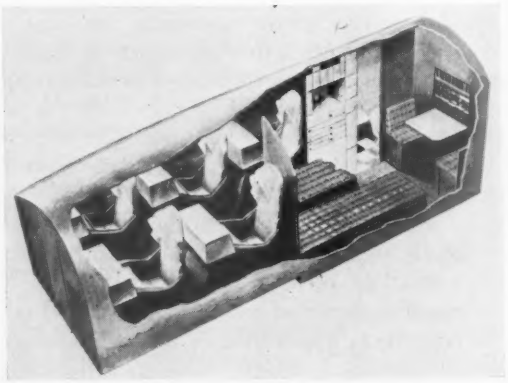


Fig. 4. Crew endurance simulator.

(1) A sustained radial acceleration field up to 20g.

(2) Three degrees of translational acceleration limited by 5g maximum acceleration, and 10 ft. maximum amplitude.

(3) Three degrees of rotational acceleration limited by 50 rad./sec./sec. maximum angular acceleration.

The capsule is mounted within a system of gimbals which permit 360° of angular rotation about each of three axes. The nominal radius of action of the capsule is 100 ft. The angular position and velocity of the capsule within the system of gimbals is controlled by hydraulic motors on each gimbal axis. The outermost gimbal ring is supported at the apex of a tripod which is composed of three linear hydraulic actuators.

Except for the outboard end of the upper actuator, which is rigidly attached to the outer gimbal ring, both ends of the actuators terminate in universal couplings. This permits the capsule to be moved in translation to any point within a 20-ft. cube.

The tripod is supported by a large vertical central shaft. The capsule and associated mechanism are counterbalanced by an opposing mass on the opposite side of the central shaft. The counterbalance is adjustable, while the accelerator is stationary, so that approximate compensation may be made for various weights and radii of the basic payload. The present philosophy is to leave the secondary motions of the payload unbalanced.

Radial loads are opposed by roller bearings at each end of the shaft. The upper bearing is supported by radial beams, which provide a tension path for the transfer of the radial bearing loads to the edge of the accelerator pit. The vertical load is reacted by a thrust bearing at the lower end of the shaft.

An electric-motor drive system, located in an area underneath the centrifuge, supplies the rotational driving torque. For the 20g conditions, the power to overcome the aerodynamic drag of the accelerator with the 8-ft. diameter capsule at a radius of 100 ft. has been calculated as 4,800 hp. when the air mass in the pit is considered static. When the stirring effect of the accelerator machinery on the air is accounted for, the steady-state power required is 1,570 hp. The power to overcome mechanical friction is negligible by comparison.

The rotational attitude and motions of the capsule within the gimbals are controlled by three electro-hydraulic servos employing the hydraulic motors and gear-train drives provided on each gimbal axis. Two-stage electro-hydraulic servo valves control the pressure, and flow to these motors in response to electrical signals from the control computer.

Sensors installed on each gimbal axis provide electrical feedback signals proportional to the angular position, velocity, and acceleration of the respective driven member. These feedback signals are transmitted to the control computer for use in computing the control signals necessary to simulate the desired flight conditions.

Fig. 5. Recording and instrumentation control center.

The control computer contains the computing cross-coupling and amplifying circuitry required to generate the control signals for rotation and translation of the capsule, as well as rotation of the centrifuge arm. These control signals are generated in response to command signals from the automatic programer, the problem director, or the test subject.

Translations of the capsule are controlled by servo control of the three tripod actuators. Electro-hydraulic valves modulate the pressure and flow to these actuators in response to electrical control signals from the control computer. Electrical signals proportional to the position and velocity of the tripod actuators are fed back to the control computer.

Control of the gaseous, visual, and aural environment within the capsule is accomplished by conventional techniques. The gaseous environment is controlled over a moderate range, sufficient to simulate emergency conditions tolerable to man.

The external visual environment is presented within the capsule by a television screen. The television picture is generated by the controlled movement of a television camera relative to a scale model of the required external visual environment. Required internal instrumentation displays are controlled by the computer system.

Data and power transmission to and from the capsule is accomplished by use of both slip rings and telemetry.

Mid-Course Phase

This phase requires accommodation of several crew members for long periods of time. A capability of representing a zero-*g* field is highly desirable, but, as will be shown later, the available concepts for simulation of zero-*g* are not compatible with other aspects of this phase. For this reason, two simulator types are necessary. These will be identified as a crew endurance simulator and a null-*g* simulator.

Crew Endurance Simulator—Several simulators are in existence for the study of problems associated with long-term confinement of crews. Experience with the

During experimental runs, individual crew member performance and condition are monitored by four means as follows:

(1) The performance task panels.

(2) A bioelectric harness worn by each crew member which measures six physiological factors.

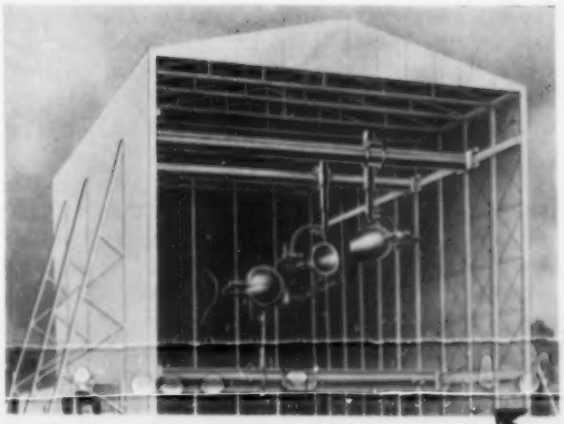
(3) Biochemical analyses of waste materials.

(4) Visual observation through one-way ports in the walls of the crew compartment.

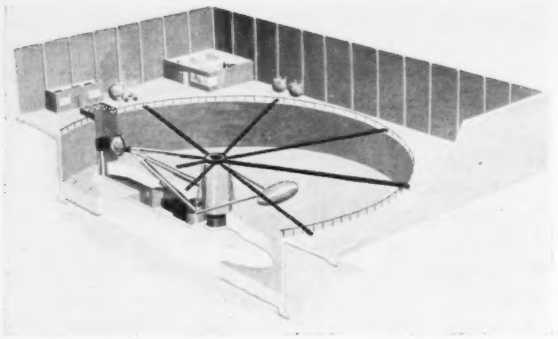
The control center shown in Fig. 5 is equipped to record task performance and bioelectric data for each crew member. Control of the tasks to be presented on the crew-compartment panels is also provided at this center.

Null-Gravity Simulator. The principal technique employed to account for simulation of [illegible]

located near the center of rotation. Each body segment is either weighted or buoyed in order to provide a net density of each segment equal to that of the water. The breathing air-supply inlet and exhaust are controlled to prevent bubble leakage into the tank, since this would provide an undesirable visual reference. The tank, the water, and the man rotate at the same angular velocity. The man is loosely constrained by cables attached to his body, so that rapid recovery can be achieved by reeling the man against the large entry door. In recovery of the man, the tank is stopped with the door on the top side, as shown in the figure, after which the door is rotated outward, thus removing the man from the water.



Controls and displays are provided to permit evaluation of test subject performance. Either a generalized



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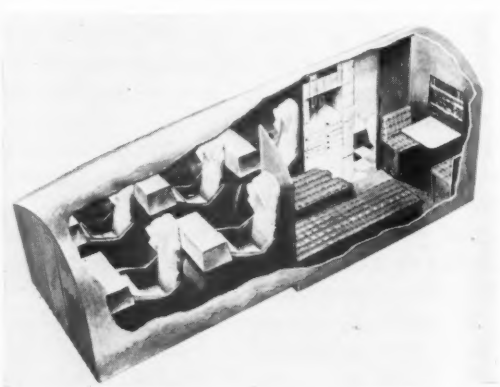

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(3) Three degrees of rotational acceleration limited by 50 rad./sec./sec. maximum angular acceleration.

The capsule is mounted within a system of gimbals which permit 360° of angular rotation about each of three axes. The nominal radius of action of the capsule is 100 ft. The angular position and velocity of the capsule within the system of gimbals is controlled by hydraulic motors on each gimbal axis. The outermost gimbal ring is supported at the apex of a tripod which is composed of three linear hydraulic actuators.

Except for the outboard end of the upper actuator, which is rigidly attached to the outer gimbal ring, both ends of the actuators terminate in universal couplings. This permits the capsule to be moved in translation to any point within a 20-ft. cube.

The tripod is supported by a large vertical central shaft. The capsule and associated mechanism are counterbalanced by an opposing mass on the opposite side of the central shaft. The counterbalance is adjustable, while the accelerator is stationary, so that approximate compensation may be made for various weights and radii of the basic payload. The present philosophy is to leave the secondary motions of the payload unbalanced.

Radial loads are opposed by roller bearings at each end of the shaft. The upper bearing is supported by radial beams, which provide a tension path for the transfer of the radial bearing loads to the edge of the accelerator pit. The vertical load is reacted by a thrust bearing at the lower end of the shaft.

An electric-motor drive system, located in an area underneath the centrifuge, supplies the rotational driving torque. For the 20*g* conditions, the power to overcome the aerodynamic drag of the accelerator with the 8-ft. diameter capsule at a radius of 100 ft. has been calculated as 4,800 hp. when the air mass in the pit is considered static. When the stirring effect of the accelerator machinery on the air is accounted for, the steady-state power required is 1,570 hp. The power to overcome mechanical friction is negligible by comparison.

The rotational attitude and motions of the capsule within the gimbals are controlled by three electro-hydraulic servos employing the hydraulic motors and gear-train drives provided on each gimbal axis. Two-stage electro-hydraulic servo valves control the pressure, and flow to these motors in response to electrical signals from the control computer.

Sensors installed on each gimbal axis provide electrical feedback signals proportional to the angular position, velocity, and acceleration of the respective driven member. These feedback signals are transmitted to the control computer for use in computing the control signals necessary to simulate the desired flight conditions.

Fig. 5. Recording and instrumentation control center.

The control computer contains the computing cross-coupling and amplifying circuitry required to generate the control signals for rotation and translation of the capsule, as well as rotation of the centrifuge arm. These control signals are generated in response to command signals from the automatic programer, the problem director, or the test subject.

Translations of the capsule are controlled by servo control of the three tripod actuators. Electro-hydraulic valves modulate the pressure and flow to these actuators in response to electrical control signals from the control computer. Electrical signals proportional to the position and velocity of the tripod actuators are fed back to the control computer.

Control of the gaseous, visual, and aural environment within the capsule is accomplished by conventional techniques. The gaseous environment is controlled over a moderate range, sufficient to simulate emergency conditions tolerable to man.

The external visual environment is presented within the capsule by a television screen. The television picture is generated by the controlled movement of a television camera relative to a scale model of the required external visual environment. Required internal instrumentation displays are controlled by the computer system.

Data and power transmission to and from the capsule is accomplished by use of both slip rings and telemetry.

Mid-Course Phase

This phase requires accommodation of several crew members for long periods of time. A capability of representing a zero-*g* field is highly desirable, but, as will be shown later, the available concepts for simulation of zero-*g* are not compatible with other aspects of this phase. For this reason, two simulator types are necessary. These will be identified as a crew endurance simulator and a null-*g* simulator.

Crew Endurance Simulator—Several simulators are in existence for the study of problems associated with long-term confinement of crews. Experience with the

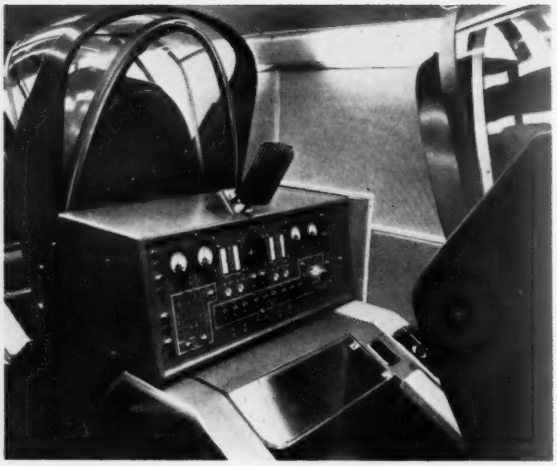

Fig. 6. Task performance panel.

operation of nuclear submarines has also provided much valuable data in this area. The simulator to be described here is operated by the Human Factors Research Department of Lockheed's Georgia Division. Construction was sponsored by the Aerospace Medical Laboratory, WADD.

The crew endurance simulator consists primarily of the crew compartment, which is shown by Fig. 4, and the recording and instrumentation control center shown by Fig. 5.

The crew compartment is divided into a work area and a leisure area. Five work stations are provided in the forward section of the compartment. Each station is equipped with a generalized task-performance panel as shown by Fig. 6. The tasks are representative of functions demanded of flight-system operators and include the following:

(1) Tracking.
(2) Mental computation.
(3) Pattern discrimination.
(4) Instrument-pointer position monitoring.
(5) Probability monitoring.
(6) Warning light monitoring.
(7) Auditory monitoring.

Both the composition of the work load, in terms of these tasks, and the rate at which tasks are presented can be varied over a wide range.

The leisure area is located in the aft section of the compartment. A food bar and a toilet area are located on the right-hand side of the compartment. The rear of the leisure area is occupied by two seats and a folding table. The left side of the cabin accommodates two bunks. In recent experiments with this simulator, the two bunks have been removed and sleeping accommodations for six crew members provided within a connecting compartment area.

Air to the compartment is conditioned to give near optimum temperature and humidity. The walls of the compartment are soundproofed to reduce leakage of external noise. Radio and recordings are provided for entertainment.

During experimental runs, individual crew member performance and condition are monitored by four means as follows:

(1) The performance task panels.
(2) A bioelectric harness worn by each crew member which measures six physiological factors.
(3) Biochemical analyses of waste materials.
(4) Visual observation through one-way ports in the walls of the crew compartment.

The control center shown in Fig. 5 is equipped to record task performance and bioelectric data for each crew member. Control of the tasks to be presented on the crew-compartment panels is also provided at this center.

Null-Gravity Simulator—The principal technique employed presently for simulation of a zero-g state utilizes an aircraft which is flown in a controlled trajectory. The major shortcoming of this system is the limited time during which a very low or zero-g state can be maintained—less than a minute.

A technique suggested by Nobel Laureate Muller[2] is currently being exploited in a simulator being built by the aforementioned Human Factors Research Department. This simulator will permit the representation of many of the physiological and psychological aspects of weightlessness for extended periods of time. It is primarily adaptable to a single test subject.

This technique provides for the immersion of a man in water to deprive him of the sensory cues resulting from muscular tension and pressure points. Cues from the otolith organs of the inner ear, which sense acceleration directly, are nullified by rotating the man within the support fluid about his long axis in a horizontal plane. It is anticipated that the response rate of the otoliths is such that even for relatively low rotational rates, less than 80 r.p.m., the gravitational field will not be perceived. This will leave the man with only visual reference for orientation.

Fig. 7 shows a representation of the null-g simulator. The cylindrical tank, filled with water, is rotated at a controlled rate about its long axis. The test subject is

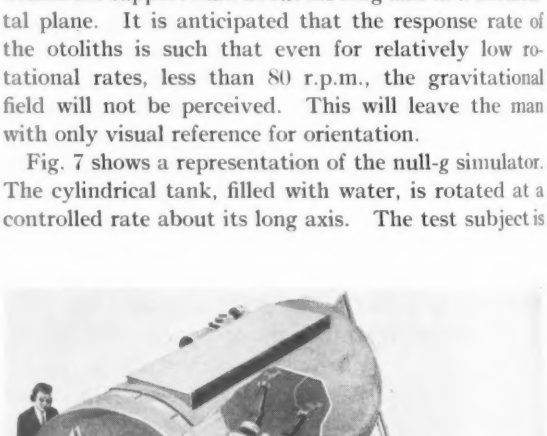

Fig. 7. Null-gravity simulator.

located near the center of rotation. Each body segment is either weighted or buoyed in order to provide a net density of each segment equal to that of the water. The breathing air-supply inlet and exhaust are controlled to prevent bubble leakage into the tank, since this would provide an undesirable visual reference. The tank, the water, and the man rotate at the same angular velocity. The man is loosely constrained by cables attached to his body, so that rapid recovery can be achieved by reeling the man against the large entry door. In recovery of the man, the tank is stopped with the door on the top side, as shown in the figure, after which the door is rotated outward, thus removing the man from the water.

Controls and displays are provided to permit evaluation of test subject performance. Either a generalized performance task panel, as shown by Fig. 6, or a specific task panel may be installed. A TV screen is provided to serve as an input of external visual references.

The experiment controller's station provides controls for reeling the man in and out, stopping the tank, and dumping the water in an emergency. A closed-circuit TV system provides the controller with visual contact with the test subject at all times. The entry door is manually opened from the outside.

Terminal Mission Phase

In consideration of the requirements for simulating the environmental situations of space-station construction, the following ground rules were used in the investigation of the concept to be described.

(1) Provision for suspending three bodies simultaneously such as to permit each body to have six degrees of freedom of movement in simulation of undamped motion.

(2) Provision for movement of the following characteristics: (a) *Linear movement*—50 ft. vertically, 100 ft. laterally, and 200 ft. longitudinally. *Maximum velocity*—30 ft./sec.; *maximum acceleration*—2*g*. (b) *Angular movement*—360° of rotation about all axes. *Angular velocity*—3.0 rad./sec.; *angular acceleration*—4.0 rad./sec./sec.

(3) Provision for supported bodies of 2,000 lbs. maximum weight. Clearance provisions for a 10-ft. diameter sphere.

(4) Provision in the computer and control system to permit adjustment of the simulated mass and moment of inertia of the bodies being suspended, and adjustment of the control responses of the manned vehicles represented.

The simulator is shown in Fig. 8. Two suspension systems are supported by overhead tracks; a third suspension system is supported by tracks near the ground level. In the figure, the lower suspension system is shown supporting a manned assembly vehicle, while the upper suspension systems support the two halves of a cylindrical compartment to be assembled.

Each suspension system provides for movement of the supported body in three degrees of translation and three degrees of rotation. Each of the six degrees of

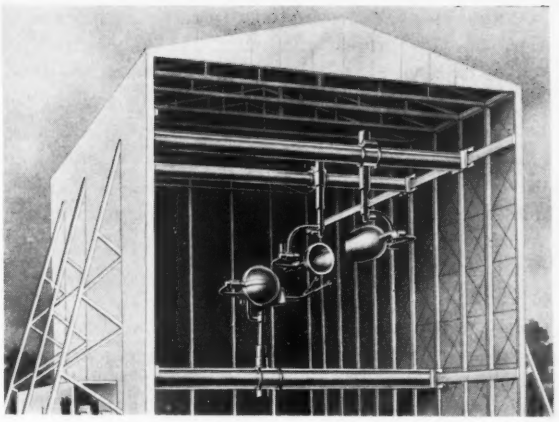

Fig. 8. Space assembly simulator.

motion is controlled in velocity and position by a positive drive system which receives its control signals from the computer system. The 200 ft. of longitudinal travel of the suspension systems is provided by movement of each assembly along tracks running the full length of the building. The 100 ft. of lateral movement is provided by a trolley which moves along a cylindrical bridge. One end of a telescoping tube, which affords 50 ft. of vertical movement of the suspended body, is attached to the trolley. The telescoping tube is supported at one side of the trolley so that the two bodies suspended from the overhead systems can make contact before the corresponding bridges engage. The tube is composed of three hydraulic cylinders in tandem.

A gimbal system which permits rotation of the suspended body through 360 deg. about three axes is attached to the telescoping tube. Each of the gimbal axes is driven by an electric motor and gear train. When the gimbal axes are normal to each other, yaw in the conventional sense results from rotation of the outer gimbal about an axis coincident with the telescoping support. Pitch is provided by rotation of the inner gimbal about the end of the outer gimbal. The roll axis is supported at one end of the inner gimbal. Cantilever-type gimbals are used in order to reduce the vehicle area blocked by the gimbal system.

Vehicle motions can be initiated by the application of an external force to the vehicle. The direction and magnitude of such forces are determined by six sets of strain gages, which are installed in such a manner as to pick up the torque at each of the three gimbal axles and the thrust along each of the three gimbal axles.

The test subject can be provided with control of all motions of his vehicle. Provisions are made for bringing out independent control signals for each degree of freedom so that various configurations of control systems can be simulated.

The computer system calculates the velocities and accelerations which would result in space from both the interbody forces and the vehicle operator inputs to the control system. Signals are then transmitted to

the appropriate servo systems to result in representation of the proper motions. The computer also makes the coordinate transformations which are necessary, and limits the translational velocity and the collision velocity between bodies.

A 400-hp. electric motor is used on all translational drives. In simple sinusoidal motion, this power permits a maximum acceleration of 2*g*, and a maximum velocity of 10 ft./sec. for the traveling bridge which provides longitudinal motion, a maximum acceleration of 2*g*, and a maximum velocity of 30 ft./sec. for the trolley which provides lateral motion, and a capability in excess of 2*g* acceleration, and 30 ft./sec. for vertical motion. A 50-hp. electric motor is used for the rotational axes.

A preliminary investigation indicates that this is adequate to produce the maximum vehicle angular velocity and acceleration specified by the ground rules simultaneously and in any arbitrary plane provided, the pitch never exceeds 65 deg. This limitation results from use of only three rotational centers. When the pitch reaches a value of 90 deg., two of the gimbal axes are coincident and one degree of freedom of rotation is lost. When this condition is approached, the velocity required of two of the gimbal drive motors tends toward infinity. The exclusion of this area from the permissible movements of the vehicle is not considered a particularly serious handicap. The addition of another gimbal would eliminate this problem but would impose additional complexity.

During the operation of the simulator, it is desirable to communicate with the occupant of the suspended vehicle, and to observe and record information indicative of his performance. A number of data-transmission channels from the vehicle to a convenient stationary observation post are provided for these purposes.

Only the power supply to the vehicle, and the control signals from the vehicle will be carried by direct wiring. Slip rings at the gimbal axes provide the electrical path.

The external visual environment may be composed of any of the following elements: other vehicles or man-made bodies; the earth and associated objects; the sun; the moon; and more distant celestial bodies.

Representation of the earth may be achieved by photographic projection of the required visual field on the walls or floor of the simulator room.

The sun and moon may be simulated by appropriate focusing or diffusing of a high-intensity arc light. This light may be fixed at some point within the room, or it may be supported by one of the suspension systems.

The more distant celestial bodies may be represented by a large number of small low-intensity lights scattered about the room or by projection on a screen.

The simulators and the interior of the building will be painted dull black in order to minimize scattered light.

The aural environment may easily be provided by use of recorded noise when such is desirable. The exclusion of undesirable external noise will require soundproofing of the vehicle.

Conclusions

Existing facilities do not provide the simulation capability required for full exploitation of man's capabilities in future space flight systems. Technologically, such capability is presently attainable. Active steps to alleviate this shortcoming will be in keeping with the philosophy of maximum attainment for a fixed economic endeavor.

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Surface Effects on Materials

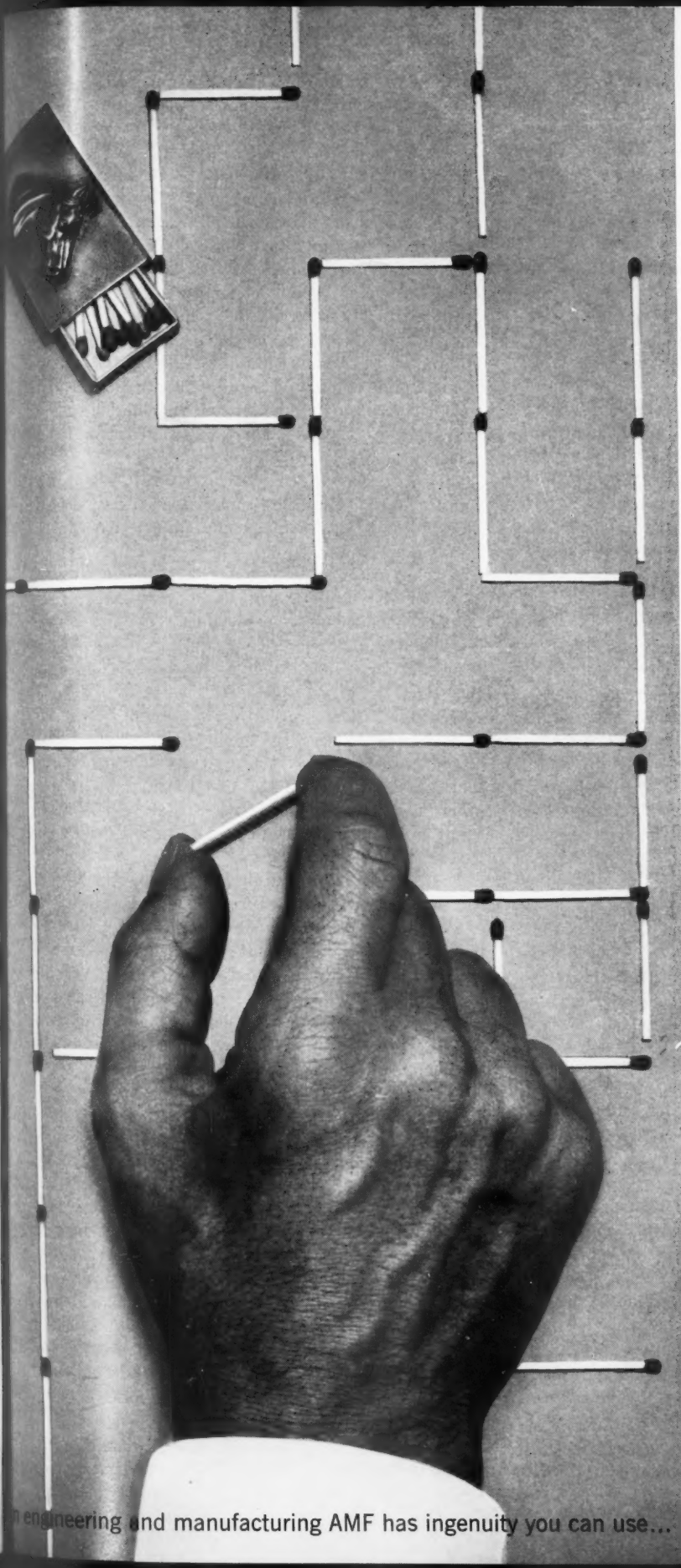
(*Continued from page 19*)

ites, or interplanetary dust particles[9] with diameters on the order of several microns, will be about 30 per year per sq.cm. for an object traveling just beyond the earth's atmosphere, with some possibility for as many as 300 impacts per year per sq.cm. Measurements from the Explorer satellites vary between 30 and 300,000 impacts per year per sq.cm., subject to some doubt because there was no instrument calibration. Impact velocities can be as high as about 180,000 miles per hour.

Even if the environment were known more exactly, there would still remain the problem of determining its effects on surfaces. Micrometeoric erosion is difficult to simulate. Laboratory experiments have been an order of magnitude too low on velocity, and three orders of magnitude too high on the size of impacting particles. Also, unlike the larger and denser particles that are responsible for shooting stars, and unlike the solid pellets used in laboratory experiments, many micrometeorites are believed to be very light and fragile, with densities less than 0.05 gm. per cu.cm. All of this makes it difficult to extrapolate laboratory tests to space conditions.

A second kind of erosion is that due to sputtering, or erosion due to the impact of high-velocity ions, atoms, or molecules, in which the eroded material is ejected from the surface in the form of single atoms or molecules. Sputtering was first encountered in vacuum electronic tubes—the so-called cathode sputtering—where high-energy ion bombardment caused the gradual erosion of vacuum-tube elements and their eventual failure.

Considerable research has been devoted to sputtering,[10] but, as in the case of micrometeoric erosion, it is



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not certain how serious a problem sputtering will be from spacecraft surfaces. Among the unknowns are the threshold energies (the minimum energies needed by the impacting particles to dislodge surface atoms), the yield ratio (the number of ejected particles per incident particle of a given energy), and the dependence of these two factors on the angle at which the impacting particles strike the surface.

Research to measure these quantities and to study the basic mechanism of sputtering should also consider the effects of surface films. Oxide films, for example, are known to reduce sputtering from metallic surfaces, and they offer this added advantage when used for temperature-control coatings.

A third possible cause of surface erosion is solar corpuscular radiation, and this may be more important than sputtering or micrometeoric erosion.

Erosion by Van Allen radiation is probably not important. The proton flux in the inner belt appears too small, and electrons, which comprise the remainder of the inner belt and probably all of the outer belt, cannot cause erosion.

Summation

In summing up the situation for temperature-control surfaces, one needs to know not only the original optical properties—that is, such things as the alpha-over-epsilon ratio for freshly prepared surfaces—but also the optical properties after prolonged exposure in high vacuum while subjected to heat, high-energy electromagnetic radiation, and various types of erosion. Establishing the environmental conditions in space more exactly by future satellite flights and simulating these conditions in the laboratory will both be necessary.

Wear and Seizure of Rubbing or Sliding Surfaces

Background

A second major problem in surface behavior in space is that of the wear and seizure or rubbing of sliding surfaces. Lubrication is needed, not only to reduce frictional drag in moving parts and minimize the power required to drive them, but it is also absolutely essential for preventing gross seizure. The problem of seizure is due to the removal of adsorbed surface films in the high vacuum of space. Adsorbed films, a few molecules thick, are normally present even on the cleanest surfaces in the atmosphere. When they are stripped off in high vacuum, bare metal surfaces can come together in intimate contact, with the result that they cold-weld together, and can only be separated by prying them apart. Preventing such metal seizure and providing good lubrication is a problem not only with such mechanical components as gears, bearings, latches and cams, but it can also be a problem with electrical parts such as sliding contacts, relays, and switches.

Present Status

Lubrication with oils and greases in space is made difficult, first of all, by the extremely low pressure. In some ways, the problem here is similar to the high-temperature problem at normal pressures. Either heating an oil or reducing the pressure on it speeds up its evaporation. In the case of greases, the more volatile constituents distill away and leave a hard residue behind which can jam ball bearings. Frictional heating and hysteresis losses around motors raise bearing temperatures in vacuum above those at which they would normally operate in air because of the lack of convection cooling, and the higher temperatures, in turn, increase evaporation. A possible solution is to seal moving parts and to use special greases and oils that have low-vapor pressures, such as those developed for vacuum pumping and for high-temperature lubrication. Close-fitting seals would cut down on molecular flow at low pressures so that enough lubricant might be retained for a satisfactory lifetime.

Another problem is that when the pressure is reduced suddenly during launching into orbit, oil or grease can be blown out of the bearings and other parts by the escaping air stream.

A third factor at low pressures is oil loss by creep along shafts. Materials or surface coatings that are not wet by oil should be used, so that oil will not creep out of seals and flow over large surfaces, where the area available for evaporation is large and losses are excessive.

Generally, the absence of oxygen might be thought an advantage, since there would be no reaction of the oil or grease with oxygen that would degrade the lubricants and form sludge. However, there are two other factors that should be considered, both of which result from the inability to reform surface oxide films that are broken through during rubbing.

First of all, the lubrication provided by many lubricants, such as fatty acids, is really due to the formation of a metal soap as a result of chemical reaction with the metal surface. Experiments have shown that this chemical reaction takes place via the oxide film on the metal and is favored by the presence of oxygen and water. When such oxide films are worn away by abrasion of rubbing surfaces, they must be reformed if satisfactory lubrication is to be obtained. This is obviously impossible if oxygen is absent from the surrounding atmosphere, as in the vacuum of space.

The second important phenomenon is the catalytic action of clean, oxygen-free, metal surfaces in promoting certain reactions, notably the polymerization of some lubricants and other organic materials. Lubrication failures in instrument bearings have been observed to be characterized by the formation of a very heavy grease or varnish in the bearings.[11] This was felt to be due to polymerization of the lubricant, which had been catalyzed by the oxygen-free surfaces of metal that were exposed by abrasion during the operation of the bearings. Normally, oxygen-free surfaces would react soon with oxygen from the atmosphere, form an oxide coating, and stop the polymerization.

These results recall an earlier observation that explained the mysterious transient "opens" frequently ex-

perienced in switching.[12] A dark deposit was invariably found around nonarcing contacts, and studies showed that it was formed by polymerization of traces of the organic vapors that emanated from the insulating materials of the relay structure. Subsequent experiments showed that polymerization occurred with almost every class of organic compounds, including completely halogenated compounds.

A second means for providing lubrication in space is with thin films of solid lubricants. Very simply, the theory behind thin film lubrication is indicated in Fig. 2. Friction and wear are due to the welding together of surfaces at their points of contact, and to the subsequent tearing of the welded junctions when the surfaces are slid over one another. The frictional force (F) equals the product of the area of real contact (A) and the shear strength of the junction (S). When a hard, strong material rides over a soft one, the hard body presses into the soft one so that the area of contact is large, and this gives a large frictional force. The frictional force is also large when both bodies are hard, since the strength of the junctions is large, although the contact area is small. The ideal situation is to use a thin film of soft material with low shear strength between two hard bodies, so that the hard substrate supports the load and keeps the area of contact small, while the film of soft material keeps the junction strength small. Together, the two factors keep the frictional force small.

Silver has been used for many years as a soft, low shear strength metal to provide thin film lubrication on ball bearings for rotating anode X-ray tubes. Gold has also been used in place of silver. Bearings lubricated with films of these metals can be useful in many satellite applications, provided that their wear lives can be improved.

Laminar compounds such as molybdenum disulfide are another class of solids that might be used for thin film lubrication. Such solids have low shear strength along certain crystallographic planes which become oriented parallel to the sliding surfaces. The structure of molybdenum disulfide contains sheets of molybdenum and sulfur atoms that alternate in the sequence S:Mo:S:S:Mo:S:S . . . . This has been likened to a stack of bread in which the slices have been buttered on both sides—the bread slices represent planes of molybdenum atoms and the butter, the planes of sulfur atoms. Butter portrays the action of sulfur well—it sticks to the surface and slides easily.

Research has shown that sulfur is released at the interfaces during sliding and does much the same job for MoS_2 as water vapor does for graphite.[13] Graphite, as is well-known, does not lubricate in vacuum even though it has a lamellar structure and functions well in air. The difficulty with graphite is that its lubricity depends upon adsorbed water vapor, which is stripped away in vacuum, so that graphite simply grinds away to carbon dust. However, the sulfur atoms in MoS_2 are part of its structure and they are not lost in vacuum, so that MoS_2 does provide good lubrication in vacuum.

Some disadvantages of solid films are discussed in the following paragraphs.

First, one of the main problems is obtaining good adhesion. Surface preparation is important, and can change the endurance life by several orders of magnitude. Phosphatizing treatments, chemical etching, and vapor blasting are among the treatments used. For thin metallic films, vacuum deposition often gives better adherence than deposition from chemical solutions. Lamellar solids, like molybdenum disulfide, are commonly bonded with thermosetting resins. Silicone and epoxy binders used in commercial films are cured by heating the coated parts to temperatures on the order of 300°F. The steel or other material being coated must, of course, be dimensionally and metallurgically stable when heated to the curing temperature. The stability of organic binders under high vacuum and radiation is still questionable, and inorganic binders are desirable.

Second, thin films of solids are not so long-lived as fluid lubricant systems, wherein the fluid can be constantly changed and renewed. Thin films eventually wear through and are not self-healing. Simply putting on a thicker film does not solve this, since the thicker films have poorer adherence and, if films on ball bearing races are too thick, for example, the bearing will jam. Metal films can be periodically renewed before they wear through by evaporating additional metal on to the surface from a heated filament, but such a system introduces additional complexities.

Third, although solid lubricants have very low coefficients of friction, they still do not get down as low as normal fluid lubrication is able to do. This means more power to overcome frictional drag.

Fourth, and in line with the third item, more frictional heat will be generated than with fluid lubrication, and it will be more difficult to get rid of it than if there were a flowing stream of oil that also served as a coolant. Add to this the fact that there will be no heat loss by convection to the air, and one can expect that sliding parts will experience higher temperatures in space. Intermittent operation, such as operation for a few minutes per orbit, is helpful in keeping temperatures down.

Despite this list of disadvantages, solid film lubricants still offer many advantages for satellite systems.

Several plastics, such as Teflon and nylon, have been used in the past in gears and bearings, and offer interesting possibilities as self-lubricating solids on spacecraft.

Teflon, or polytetrafluoroethylene, is a soft but tough thermoplastic that melts at 620°F. and has a slippery feeling. Its coefficient of friction is about 0.04, or less, which is the lowest coefficient of any known solid. Its resistance to deformation and wear are both improved by adding reinforcing agents such as graphite, powdered glass, MoS_2, or metal fibers. Porous metals whose surfaces have been impregnated with Teflon have coefficients of friction similar to Teflon alone, and have excellent resistance to wear. Most Teflon bearings are sleeve bearings, although ball bearings with alternate

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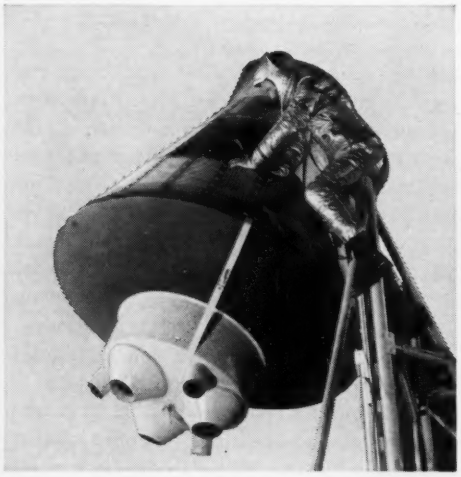
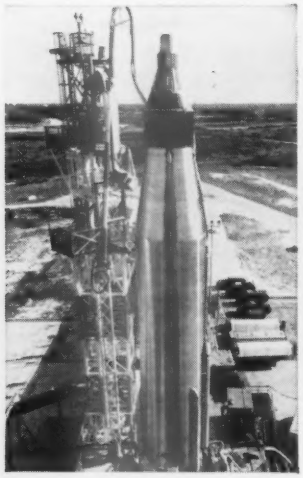


Mock-up of Project Mercury capsule, built by McDonnell Aircraft Corporation for the manned orbital flight program of the National Aeronautics and Space Administration.



In "Big Joe" test launching, full scale model of Mercury space capsule was boosted 100 miles high atop this Air Force Atlas missile. Capsule was protected by a B. F. Goodrich laminated glass fibre and resin heat shield fabricated under subcontract to General Electric.

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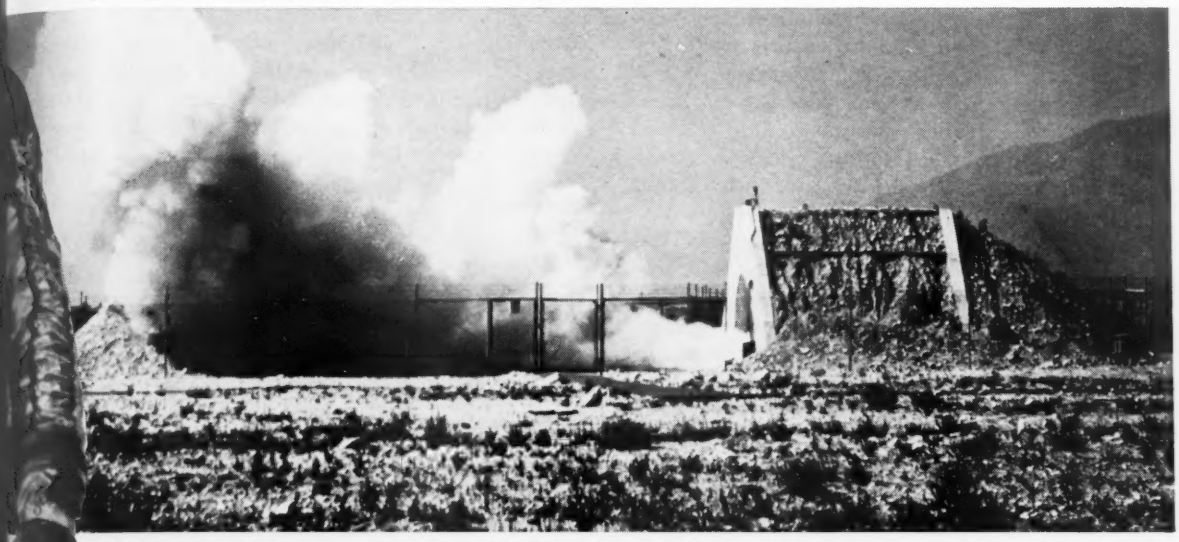

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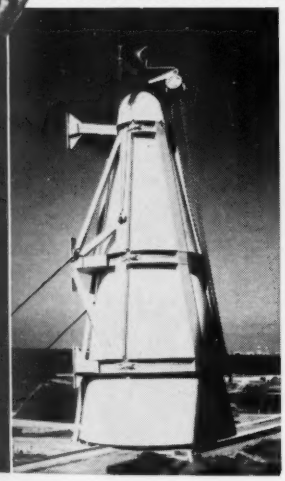

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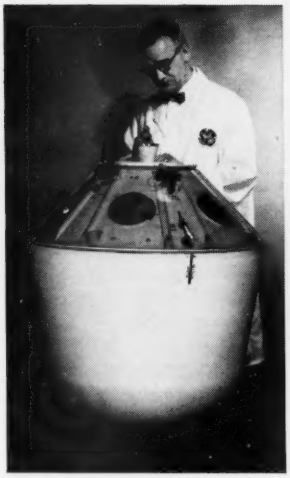
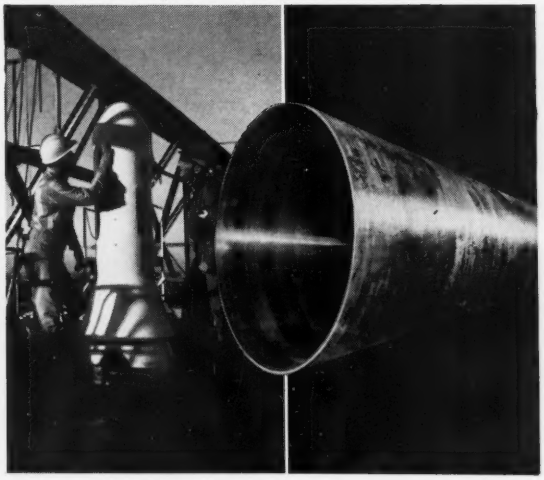


Satellite Aeromedical Re-entry/ Recovery Vehicle for USAF Discoverer Program.



Mark-3, an advanced operational-type re-entry vehicle for the Air Force Atlas.

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balls of Teflon and metal, or with retainers coated with Teflon, are available.

Nylon is a harder plastic than Teflon but does not have as low a coefficient of friction. Sintered nylon is available that is produced by powder metallurgy techniques from nylon powders that have been precipitated from solution; its frictional and wear qualities are superior to molded nylon. Various additives, including molybdenum disulfide, can be blended with the fine nylon powders, and this further improves the wear, abrasion resistance, and frictional characteristics.

Disadvantages with both Teflon and nylon are poor radiation stability, outgassing, and (for Teflon) the release of hydrogen fluoride vapor at slightly elevated temperatures and reduced pressures.

A second group of self-lubricating solids are porous compacts that have been impregnated or infiltrated with a lubricant. This includes not only porous metals that have been caused to soak up low-vapor pressure oils or greases, but also compacts containing solid lubricants such as silver, molybdenum disulfide, or Teflon. Such materials have been produced experimentally and have demonstrated good friction and wear.

A final approach to minimizing seizure in high vacuum is to use widely dissimilar materials, such as glass, sapphire, pyroceram, or carbides in contact with steel or other metal parts. Instrument bearings and other applications involving low loads and low speeds have used such materials for the balls and races. These materials are quite brittle, of course, and therefore have definite limitations. Balls of these materials, for example, tend to shatter under heavy loads. The limiting factors in using these solids in satellite systems will most likely be the high impact loads and vibration during launching. Hard, carbide surfaces on a tough, steel backing appear a good compromise for gear teeth and ball bearing races.

Future Requirements and Areas for Development

There are several possible approaches and a wide assortment of promising materials for providing lubrication and preventing seizure in space. Each has certain disadvantages as well as advantages, and there is practically no data on which to base a selection. In addition to operating satisfactorily in a nearly perfect vacuum, the system must also survive radiation and the high shock and vibration loads of launching. On the credit side, the problem is made considerably easier by the zero gravity in space, so that once in orbit, there are no heavy loads to support.

The most important areas for future research on the wear and seizure of rubbing surfaces will be material development and endurance tests that will establish the wear rates and lifetimes of parts with appropriate types of lubrication and under space conditions.

Conclusion

In concluding this review of surface behavior in space, it hardly seems necessary to emphasize that environmental testing will be increasingly important in determining and guaranteeing the reliability of satellite systems as these systems become more and more complicated, and as their lifetimes and their exposures to the space environment become longer and longer. Ideally, environmental tests should reproduce the various elements of the space environment completely and exactly. Since the space environment is not known completely and cannot be duplicated exactly in the laboratory, however, material tests must ultimately be conducted in space. Only from such studies can information be obtained for applying materials efficiently without fear of their degradation by unknown factors, or without overdesign to compensate for our ignorance of their behavior in the actual space environment.

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Erratum

The authors of "Refractory Materials—Part II," Aerospace Engineering for July, pages 39–44, report an error in Fig. 16 of their contribution. Specifically, the thermal conductivity curves shown for boron nitride are lower by a factor of ten from the reference data.

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Optimum Rocket Trajectories

(Continued from page 21)

parison arcs. If it is not adjoined, the Euler equations of the problem are

$$\left.\begin{aligned}(\partial T/\partial x) - (\partial V/\partial x) &= 0\\ \partial T/\partial v &= 0\end{aligned}\right\} \qquad (18)$$

If we assume $T = (1/2)v^2$, $V = gx$, $(g \neq 0)$ Eqs. (18) become $g = 0$, $v = 0$; if we assumed $V = (1/2)x^2$ but retained the form of T, we would have $v = 0$, $x = 0$. In both cases the conclusions are absurd; in the first, the result $g = 0$ implies the nonexistence of a gravitational potential; in the second, the equations of static equilibrium result. Both examples imply that there are no acceleration terms in the equation of motion (a drastic revision of Newton's second law) and in neither case can the initial conditions be satisfied unless $x_0 = v_0 = 0$.

In some of the papers,[3, 4] the kinematic constraint was introduced *after* the Euler equations had been derived. If we were to follow the same procedure here, we would obtain $\dot{x} = 0$. Then, the first of our examples yields $g = 0$, $x = x_0$, and the second, $x = 0$, $x = x_0$. Neither yields physically tenable or mathematically consistent results, and neither admits any motion whatever.

Solving the problem of Eqs. (15) to (17) correctly, we adjoin the kinematic constraint and seek the unrestrained extremum of

$$\int_0^\tau [T - V + \lambda(v - \dot{x})]\, dt \qquad (19)$$

The Euler equations of this problem are

$$\left.\begin{aligned}(\partial T/\partial x) - (\partial V/\partial x) + \dot{\lambda} &= 0\\ (\partial T/\partial v) + \lambda &= 0\end{aligned}\right\} \qquad (20)$$

If λ is eliminated between Eqs. (20), and v is replaced by $\dot{x}$, Lagrange's equation of motion

$$(d/dt)(\partial T/\partial \dot{x}) - (\partial T/\partial x) + (\partial V/\partial x) = 0$$

is obtained. In the first of our examples, the equation of motion becomes $\ddot{x} + g = 0$, and in the second, $\ddot{x} + x = 0$. Clearly, no difficulty arises in either case with respect to satisfying the initial conditions.

Finally, it should be emphasized that the constraint Eq. (17) need not be introduced by means of an undetermined multiplier. It could be imbedded directly in the integral by writing

$$\int_0^\tau f(t, x, v)\, dt = \int_0^\tau f(t, x, \dot{x})\, dt$$

The central point of this note is *not* that the kinematic constraints must be introduced by means of Lagrangian multipliers, but rather that they may not be ignored.

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Controlled Radial Energy Gradient

(Continued from page 23)

flow). Therefore, the "special way" of controlling the energy gradient which this note proposes to illustrate is to keep the axial velocity constant, obtain equal work at all radii, and account for simple radial equilibrium without having free vortex flow and its resulting mass flow limitations.

The procedure will be to list all the conditions being imposed, show the analytical development, and write the resulting equations.

It will be assumed that in a preliminary design the following conditions will be imposed upon the compressor:

(1) Equal work done at all radii (in all stages except the first).

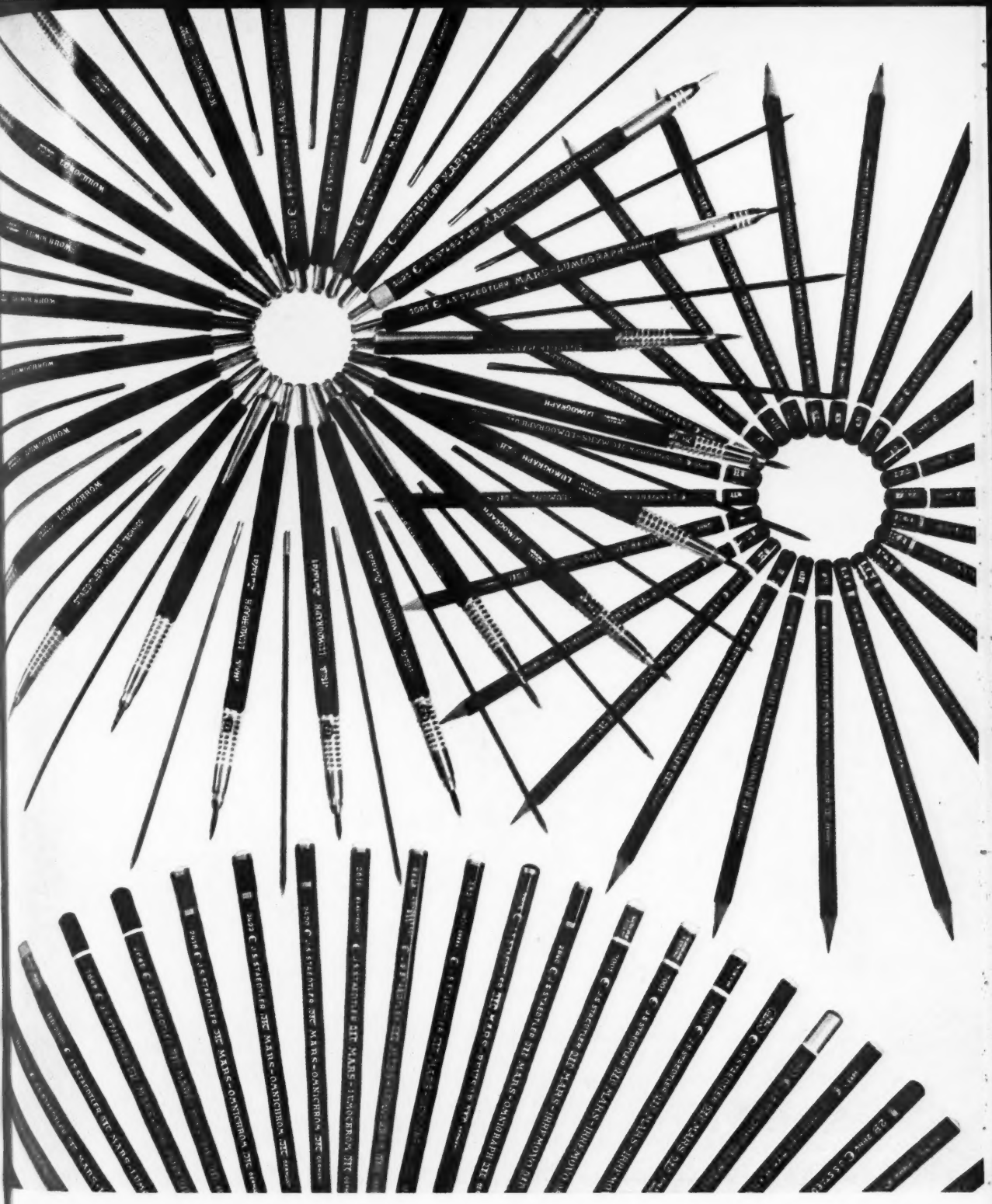
(2) Axial velocity invariant with radius.

(3) Simple radial equilibrium.

(4) Fifty per cent constant reaction staging* ($\Delta p_{\text{stator}} = \Delta p_{\text{rotor}}$).

If a special first stage is used, the entering enthalpy gradient to later stages is at the designer's discretion. This concept is mentioned in many textbooks, but only a sentence or two is devoted to it. The purpose of this

* Since the first three conditions listed exist also for free vortex flow and since in this analysis $dh_0/dr \neq 0$, the designer then has an additional degree of freedom—that is, fixing the value of dh_0/dr. By selecting the type of staging, this value is fixed.



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paper is to carry the idea further and present one possible approach to the design of a machine utilizing this concept.

The following equations will be used in the analytical development:

Energy equation $h_0 = h + (C^2/2)$ (1)

The gas law $p = \rho RT$ (2)

$dh = c_p\, dT$ (3)

Isentropic relationship $0 = du + p\, dv$ (4)

Definition of enthalpy $h = u + pv$ (5)

Simple radial equilibrium $dp/dr = \rho(C_u^2/r)$ (6)

From Eqs. (1) and (5),

$$h_0 = u + pv + \frac{C_x^2 + C_u^2}{2}$$

$$dh_0 = du + p\, dv + v\, dp + \frac{d(C_x^2)}{2} + \frac{d(C_u^2)}{2}$$

Introducing Eq. (4),

$$dh_0 = v\, dp + \frac{d(C_x^2)}{2} + \frac{d(C_u^2)}{2}$$

Dividing by dr,

$$\frac{dh_0}{dr} = \frac{dp}{\rho dr} + C_x \frac{dC_x}{dr} + C_u \frac{dC_u}{dr}$$

Introducing condition (6),

$$\frac{dh_0}{dr} = \frac{C_u^2}{r} + C_x \frac{dC_x}{dr} + C_u \frac{dC_u}{dr} \qquad (7)$$

For the condition of C_x invariant with r, Eq. (7) becomes

$$\frac{dh_0}{dr} = \frac{C_u^2}{r} + C_u \frac{dC_u}{dr} = \frac{1}{2r^2} \frac{d(rC_u)^2}{dr} \qquad (8)$$

This resultant equation has two conditions imposed upon it—constant axial velocity and simple radial equilibrium. It can clearly be seen that if the third condition for "free vortex" flow were imposed—namely, equal work at all radii—Eq. (8) would reduce to

$$r\, C_u = \text{constant}$$

if the entering radial energy gradient (dh_0/dr) were zero. The procedure in this paper is to assume that it is not zero (special first stage), to impose the condition of equal work at all radii (for all stages except the first), and then to determine the energy gradient necessary to have 50 per cent constant reaction staging.

With this type of approach, it is necessary to start with the second stage. For the condition of constant axial velocity, 50 per cent constant reaction staging leads to a symmetrical velocity diagram (see Fig. 1).

For conditions entering the second stage, Eq. (8) becomes

$$\frac{dh_0}{dr} = \frac{C_{u_1}^2}{r} + C_{u_1} \frac{dC_{u_1}}{dr} \qquad (9)$$

From Fig. 2, by inspection,

$$C_{u_1} + C_{u_2} = u \qquad (10)$$

From the momentum equation,

$$u(C_{u_2} - C_{u_1}) = \text{work}^* \qquad (11)$$

Combining Eqs. (10) and (11),

$$C_{u_1} = (u/2) - (\text{work}/2u) \qquad (12)$$

Substituting Eq. (12) in Eq. (9) and letting $u = r\omega$ results in

$$dh_0/dr = (r\omega^2/2) - (\text{work}/2r) \qquad (13)$$

This equation expresses the dependent variable, total enthalpy, as a function of the independent variable, radius, and two constants, the angular velocity of the machine (ω) and the work done in the second stage. A typical curve is shown in Fig. 2.

The gradient entering the second stage shows that more energy (work) must be added at the tip of the first stage than at the root. The second-stage work determines the energy gradient; however, the first-stage work will determine the actual values of total enthalpy at the various radii. Since the first stage usually does less work than the later stages in other compressors, the same principle should apply here. It should be noted, however, that, because of the gradient, enough average work should be done to avoid turbining at the root.

Conclusions

In summary, then, the above approach to axial flow compressor design permits the designer to use two-dimensional analysis for high-performance engines. In controlling the radial energy gradient, the key factor is to have axial velocity invariant with radius This makes the assumption of simple radial equilibrium quite accurate, a condition that must exit if there is no radial flow. To perfect this idea and make it an actuality, more study is necessary, especially in the off-design regime. It is felt, however, that not too many problems will be encountered since many successful engines have been designed using the two-dimensional approach. As an added attraction, this concept could lead to fabricating all blades, except the special first stage, from one die and merely cutting off the tips to vary the length from stage to stage.

* Work done on fluid in second stage at any particular radius in terms of energy/unit mass of fluid flowing; its value is constant with radius.

This method depends as much on good wind measurements as the other simpler one, although the data are used in a somewhat different manner. Data of this type,[3] available so far suffer primarily from lack of altitude resolution and accuracy. Comparison of load evaluation for a missile obtained with data in reference (3) against that obtained by a synthetic wind profile[6] indicate about 30 per cent higher loads by the statistical method[5]; but this number is probably not significant in view of the inadequacy of basic wind data.

The small-scale wind input, which produces still significant rigid body response (Fig. 5), corresponds to about 100-m. scale distance. This carries us into the regime of gusts and turbulence. A rather large amount of gust data has been gathered by airplanes (acceleration measurements) and by turbulence measurements at the ground. Shortcomings of these measurements are

(a) Data have been collected in horizontal flights at limited height and with a certain selectivity as to special weather situation.

(b) Response of airplane is primarily to vertical gusts and does not permit a really good evaluation of wind gusts. The measurements seem to indicate that a fair description of atmospheric small-scale turbulence can be obtained by assuming more or less constant relative spectral distribution of energy over various wavelengths with the two variable parameters—a scale factor for intensity (standard deviation gust) and the scale of turbulence L, which represents the average size of an eddy.

A theoretical expression for the density of the power spectrum seems to fit well with wind tunnel data, and the aforementioned airplane measurements; but numerical values for standard deviations and scale of turbulence are not really well-established. Nor is there a good understanding, as yet, of the correlation of these gust phenomena with the large-scale wind and of applicability of a similar model to larger scale atmospheric phenomena. Importance of the gust-spectrum input lies in the danger of control saturation and resonance with elastic or sloshing modes rather than the effect on structural loads. Extension of power-spectrum analysis to nonstationary input and variable coefficients remains to be established as an alternate approach to the above-mentioned matrix method.

Effects of Elastic Deformations and Propellant Sloshing Upon Stability and Control

It was mentioned previously that large missiles cannot realistically be treated as rigid bodies, but require, even in the early design stage, a careful evaluation of stiffness requirements which are in conflict with rigid body response requirements. Also, fluid motions in the containers are a potential hazard to the operation of the control system. Unfortunately, lack of space does not permit a really detailed discussion of these interesting phenomena which, because of their complexity, are less amenable to general treatment than the rigid body control problem, but require more recourse to lengthy digital or analog computations.

The sloshing phenomena are usually closer in frequency to the rigid body control frequency than the fuselage bending frequencies and might thus be expected to be the more critical phenomena. These frequencies can be obtained for reasonably simple tank shapes (rectangular, cylindrical, elliptical, circular) by hydrodynamic theory assuming an ideal fluid. The natural frequencies of a cylindrical tank[7-15] are, for example, those shown in Fig. 8. For an IRBM vehicle with 105-in. tank diameter, the lowest slosh frequency starts with 0.65 cps at take-off, and rises to 1.4 cps at cut-off, the control frequency being about 0.5 cps. Fortunately, it is not too difficult to provide a reasonable amount of internal (passive) damping of fluid oscillations, either by fixed baffles or by movable slosh supression devices, such as rigid lids following the fluid surface or swimming bodies partially submerged below the surface. While the damping efficiency of fixed baffles of moderate size can be estimated roughly by a formula given by Miles (Fig. 8), the usual procedure is investigation of sloshing motions in model tests. The damping is usually a function of the slosh amplitude. Model laws require that the following relationship be fulfilled[16]:

$$d_r = a_r^{-1/3} \, (\mu/\rho)_r^{2/3}$$

where d_r = ratio of linear scale of model to prototype, a_r = ratio of longitudinal acceleration of model to prototype (model is practically always at 1g), and $(\mu/\rho)_r$ = ratio of kinematic viscosity of model to prototype.

This is valid if surface tension is neglected. Acceleration at the ground, lower than that experienced in flight, calls for larger models. Use of heavy liquids, however, permits simulation of high accelerations with reasonably small models.

Smooth walled containers have, for small amplitudes, damping in the order of 2 per cent of critical damping; with moderate sized baffles, values around 10 per cent can be achieved and are usually satisfactory.

In addition to determination of the damping, ground tests are also valuable to verify theoretical results about natural frequencies and response to forced oscillations.

Another possible measure against fluid motions consists of subdivision of the tank by either egg-crate-type walls or coaxial cylinders or radial sector walls. These subdivisions increase the lowest slosh frequencies and reduce the amount of overall reaction upon the missile structure by virtue of the fact that motions in the individual cells are not in the same phase and tend to partially cancel each other. Theoretical formulas for the cylindrical ring tank[17] have been derived.

A favorable situation with respect to sloshing results from multitank design as used in the Saturn booster. Not only are the frequencies higher than they would be

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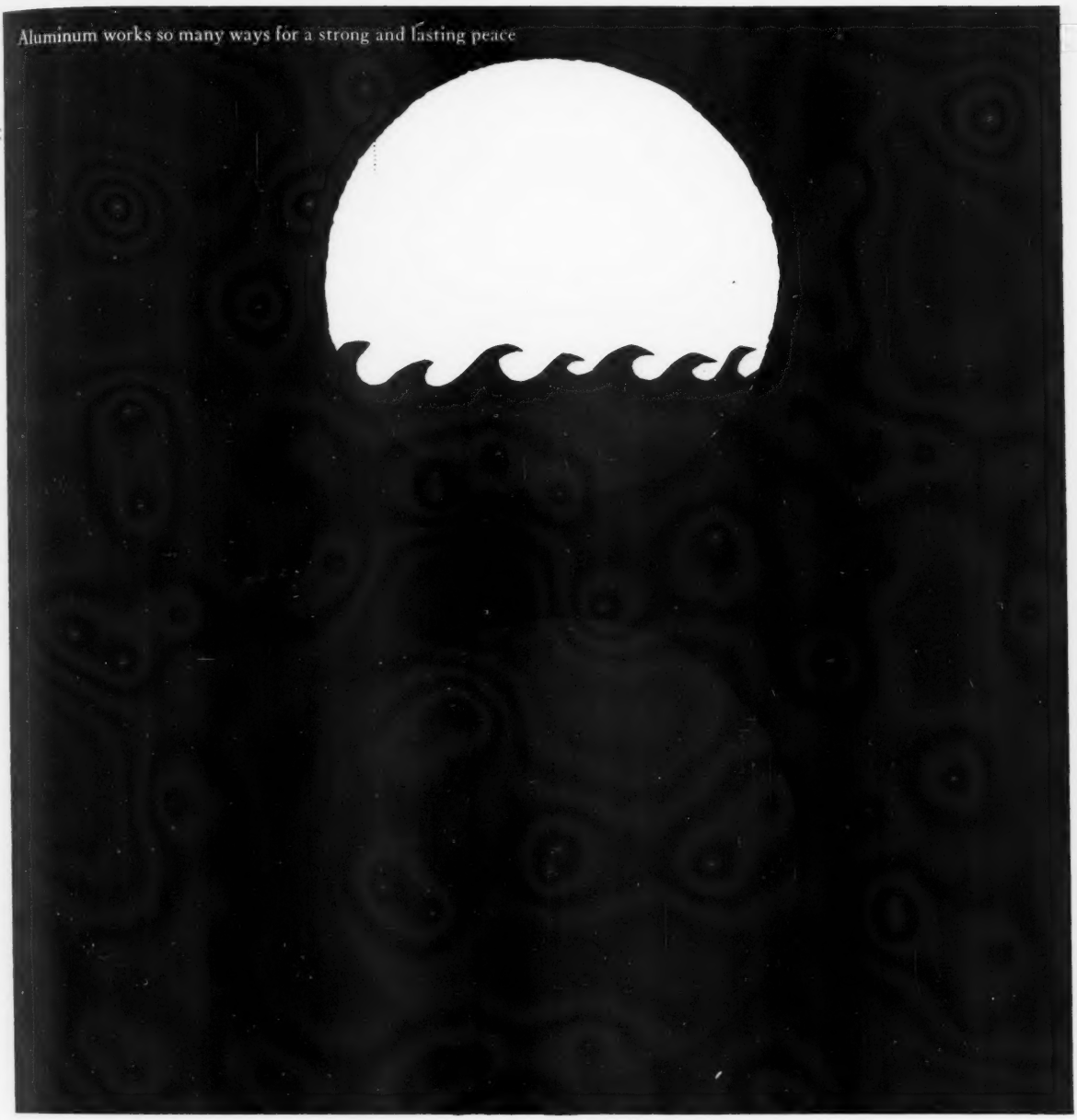

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for a single tank, but they have even different frequencies. A special phenomenon encountered here is that of an additional, very low-frequency fluid mode resulting from interchange of fluid between the interconnected tanks. However, this mode is strongly damped (the connecting pipes having a small diameter).

A certain complication arises from the fact that a coupling is produced between roll motions and pitch and yaw through fluid sloshing excited from longitudinal acceleration in the tanks at finite distance from the centerline. A simple cylindrical tank does not exhibit coupling between roll and yaw (respectively pitch) according to linearized theory for symmetry reasons, although rotational motion about the longitudinal axis has been frequently observed near resonance frequency. A theoretical explanation has been offered by Berlot[18] by analogy with a spherical pendulum.

The interaction between missile and fluid motion in containers can be described by substituting the fluid propellant mass by a fixed mass plus a sloshing mass attached to the missile walls by springs for each fluid mode. This model is accurate for ideal (undamped) motion. In case of finite damping, dashpots are added to the slosh masses, and a small modification is required to properly simulate the torques resulting from rotation of the fluid. It can probably be adequately introduced by providing a disc with finite moment of inertia which is coupled to the missile only by a torque proportional to angular speed (Fig. 9). Moment of inertia and damping of this disc are obtained from experiments with frozen surface (lid).

The equations which define all parameters of the model are given in Fig. 9.

Figs. 10 and 11 give the mass ratios and distances of the slosh masses for various ratio of fluid height over tank radius.

Theoretical analysis of a simple missile model with the slosh model attached gives some results useful for the early design phase. It indicates that instability from fluid sloshing occurs essentially only if the sloshing mass, which is not far below the fluid surface, is situated between the center of gravity of the vehicle and the forward center of percussion with respect to the control force.

The effects of elastic oscillations of the missile structure upon the control system are more critical (for large missiles) because it is hardly possible to provide internal structural damping of sufficient size to eliminate the risk of instability through interaction with the control system.

The fundamental mode of a large vehicle (of reasonable slenderness ratio) is of necessity low if the missile is designed for strength rather than stiffness, which is more or less mandatory in view of performance considerations. Gyros, angle of attack meters or (even more) accelerometers will pick up deflections of the structure and, may through feedback into the control system, produce unstable roots. The following possibilities exist for reducing this danger:

(a) Minimization of input to the sensors by proper location. An attitude gyro located at an antinode will not pick up a signal from this mode, nor will an accelerometer at a node. However, mode shapes of different modes are different, and there is no location which is satisfactory for all modes of concern. Generally the lowest modes are the most critical ones, of course.

(b) The input from the sensors into the control system at natural frequencies of the structure should have as small a gain as possible; a filtering network may achieve amplitude reduction in a sufficient degree, if the frequencies are not too close to the control frequency. Suppression of higher frequencies may be aided by a threshold in the servosystem. However, strong attenuation of input with increasing frequency by networks can be obtained usually only at the cost of deteriorating the phase gain at low frequencies. An ideal low-pass filter is not realizable by passive networks and disturbs phase relations below the cut-off frequency.

(c) Provision of phase shaping networks (in conjunction with reduction of gain) is probably the most important aspect. Theoretical analysis of the stability of all roots of the system with the original transfer function of the control system, plus a variable phase angle, permits determination of stability region and a point of optimum stability required for the shaping network. Such a procedure requires a large amount of digital work on big computers and suffers also from a certain arbitrariness with respect to assumptions about relations between phase and gain of the additional network. It does work, however, and has been used to find reasonably simple shaping networks which permit stable operation for a situation where the lowest bending frequency is about five times the value of the rigid body control model. An example of such a network and its locus curve is shown in Fig. 12, and the stability region is shown in Fig. 13. The crosshatched areas indicate values of phase lead (or lag) required for stable separation versus frequency at the various modes with the flight time given as parameter. The heavy lines correspond to the values producing optimum damping. The dotted line indicates the actual phase lag produced by the network. The K figures at the top of each stability region give the gain factor (of the network) required to produce a damping of the particular mode of 1 per cent of critical. The actual amplitudes produced by the selected network, shown in Fig. 12, are below those values at all modes, which means that the damping achieved is below 1 per cent of critical. However, low gain factors have the advantage of making the system less sensitive to unexpected shift in phase relations or characteristic frequencies. The example given here was worked out more or less by trial and error procedure concerning the network type. Systematic synthesis of shaping networks[27–29] is possible, but has not yet been adapted to the problem at hand. Reduction in computational effort and a clearer understanding of limitations of this approach make a study of this problem quite worthwhile.

A serious disadvantage in a situation such as the one quoted, and even more so in a case where the frequencies

come even closer to each other, lies in the need for rather accurate knowledge of mode shapes plus frequencies prior to testing. Theoretical prediction of these quantities becomes more difficult with increasing complexity of the missile structure. Improved methods for computing the frequencies and mode shapes by inclusion of shear forces and cross-section moment of inertia have been quite useful for IRBM type vehicles,[19] but a multitank vehicle cannot be considered as a simple beam anymore. Additional degrees of freedom are introduced and the nature of the intertank connections enters as a critical factor. Dynamic testing of a full-sized structure on the ground is costly, difficult and, most important, comes at a rather late stage of the game where modifications should be kept to a minimum. This puts a premium upon efforts for providing theoretical methods for prediction of vibrational modes of such complicated structures. Furthermore, the question to what extent small-scale tests can give reliable results is of importance. Scaling laws are simple enough, as long as the structure is well defined. It becomes problematical through such elements as connections between tanks for which no simple mathematical laws can be formulated. However, dynamic model testing is a promising field which will doubtlessly gain in scientific stature with increasing complexity of the structures to be used. In addition, models based on electric analogy may be useful to some extent.

In view of the narrow margin of safety allowed to the control design and the consequent need for elaborate structural dynamic analysis, it appears advisable to carefully explore potentialities of control systems more complex than the ones discussed—i.e., linear system with time-programed gain factors. One theoretical approach would consist in the use of multiple sensors, which, if averaged over a larger number distributed along the fuselage, could strongly reduce the input resulting from deformation. In view of the complexity, this is not considered a very attractive proposition. The superiority of adaptive control systems has been demonstrated in recent years in many cases, where wide variations of system parameters and input made operation of simple systems very difficult. Adaptive control systems may adjust their parameters in accordance with input signal characteristics, or based on measured system variables, or they may make self-adjustments based on measurement of transfer characteristics.[20, 21] Change of gain factors, according to the formula given above, based on measured dynamic pressure, is an example of the second category. (This feature would be valuable especially if large changes in normal trajectory conditions would be anticipated, such as engine failure in clustered missiles.) However, we are interested in systems which will operate well under widely varying conditions of structural feedback with frequencies not substantially higher than the basic mode. This is a tough requirement and it is not obvious whether the principles used, so far successfully, such as high-gain saturation systems,[27] switching of feedback circuitry based on signs of input and output, [23, 24] or nonlinear feedback [25, 26] will lend themselves to our problem. If the emphasis is on the uncertainty of structural feedback, it would appear that filtering techniques using active elements may produce reasonable approximations to ideal low-pass filters, and that cut-off frequencies, about three times that of the fundamental mode, should be acceptable for the rigid body problem. These remarks are offered here only as a stimulus to specialists in the field of advanced control-system synthesis, based on a feeling that this may be a fruitful avenue rather than based on analysis. It should be borne in mind though that increasing complexity of the control system tends to conflict with reliability, and careful weighing of gains in functional superiority, and consequent wider margins against the dependence on more operating elements (such as relays, amplifiers, etc.), is required by the designer of a missile control system.

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Design of Jet Transports

(Continued from page 35)

perspective, it should be noted that this arc is smaller than that between two propellers on one side of any current four-engine propeller transport, and the record to date indicates that the risk of double-engine failure on paired fuselage-mounted engines due to disc failure is less than today's propellered transports due to propeller trouble. On the positive side, there appears to be negligible chance of a turbine disc severing a fuel line, striking a passenger or striking a fuel tank—which is a useful check list. Furthermore, there should be no more problem in designing the aircraft control system and rear-fuselage structure, to avoid the possibility of a disc causing catastrophic damage, than at any other fore and aft position along the fuselage.

The question of engine fires and of compressor-blade ingestion has been dealt with in detail by a colleague, in a recent RAeS paper,[2] and, apart from the fact that both are basic design problems, which, as he demonstrates, are amenable to solution, there seems to be no need to dwell on them at length.

Perhaps the overall engine mounting situation from a safety aspect was best summed up quite recently by one of the English-speaking Certifying Authorities as follows: "If all turbine aircraft to date had been designed with their engines mounted on the rear fuselage, and then some designer or other had come to us with a proposal to mount engines on integral fuel tanks, we would have had very serious misgivings indeed at this idea."

The foregoing discussion and reference 2 have considered mainly the engineering aspects of safety, but it is worth while also to consider what rear-mounted engines offer the airline as a result of their basic crashworthiness.

(1) Reduced risk of expensive damage to the engines in minor ground accidents means a lower insurance risk and, who knows, maybe one day even reduced insurance premiums!

(2) The excellent ditching characteristics of this layout cannot be ignored, especially when it is remembered that in the U.S.A. alone at least twenty-five important airports have climb outs or approaches over water.

(3) The overall reduced fire risk, be it from belly landings, landing gear failures or tank ruptures, etc.

Crashworthiness is, in a way, slightly different from safety. Essentially, crashworthiness is called upon when basic safety provisions have either failed, been proved inadequate or human fallibility has occurred. While it is an apparently negative approach to be continually considering the possibility of a crash when designing an aircraft, nevertheless, crashworthiness is a vital asset on all aircraft and demands evaluation.

Operations

Superficially, the normal operation of rear-engined jet aircraft would appear to be negligibly different from that of their podded predecessors. The effect on airfield and cruise performance has been dealt with in other sections but, in addition, there are some side effects which are interesting.

On a short/medium range aircraft, the actual wing loading for a given airfield performance will be higher, thus passenger gust sensitivity will be reduced. Also, the optimum cost cruising altitude will be lowered, and the day to day economics, as dictated by achieved block time in high-density traffic areas, will be improved because the problems of getting up through, and down through, the traffic layers will be less.

The asymmetric trimming drag, due to engine shutdown, is clearly far smaller for the rear-mounted layout than for engines spread out along the wing, the asymmetric moment arm being some 60 per cent less on the rear-engined aircraft. This drag has never been negligible either in meeting airworthiness climb requirements with failed engines or in assessing 'points of no return' based on engine failed consumptions.

As regards the control problem inherent in all swept-wing aircraft that the rolling moment due to sideslip can be dangerous if an overswing is allowed to develop, the reassurance which a pilot feels, when his maximum asymmetric yawing moment due to engine failure is negligible, is very important. The fact that an artificial design case—i.e., cross-wind landing—has to be devised for the vertical stabilizer really exemplifies this point most effectively. Also, by eliminating pod ground clearance problems, there is no artificial (i.e., nonaerodynamic) reason for dihedral and thus the elimination of a fundamental Dutch-roll component is possible.

Loading and Balance

The rear location of the basic c.g. position and range of travel in the rear-engined layout has been seen by some as an inherent disadvantage. On the contrary, when properly defined in the initial layout, a wide and unrestrictive c.g. range can be provided, as has been shown, without compromise of other important parameters such as the tailsize.

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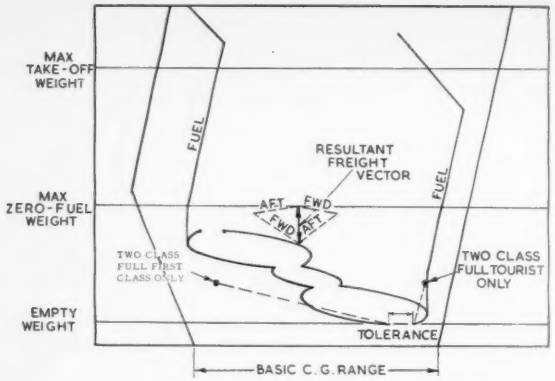

Fig. 16. Typical "rear-engined" loading diagram; window seating first.

Fig. 15 shows a conventional and typical loading loop for a podded aircraft. Fig. 16 shows the loop for a completely comparable design but with rear engines. Examination of these loops, in conjunction with Table 1, makes it quite clear that the airline operations engineer can expect rather fewer problems in the future than in the past.

The important point is that as the basic empty aircraft c.g. location of the rear engine design is almost at the rear of the range, virtually all load increments move the c.g. progressively forward through the range until the completely full stage is reached. All intermediate possibilities are thus thoroughly practical with normal methods and ramp handling uncompromised. The c.g. movement, due to fuel usage, is clearly conventional.

Where reasonable margins are allowed for engine-development weight growth, it appears neither practical nor necessary to provide adjustable or alternative engine mountings.[2]

Table 1

Loading Case	Underwing Podded Layout	Rear-Engined Layout
Empty aircraft.	No problem. Approx. center of range.	Rear limit based on this case.
Very high-density full aircraft.	No problem. Approx. center of range.	Forward limit based on this case.
One class full aircraft.	No problem.	No problem.
Full tourist. Very light first class.	Rear c.g. critical. Requires special baggage disposition.	No problem.
Full first class. Very light tourist.	Forward c.g. critical. Requires special baggage disposition.	No problem.
Partially full one class aircraft; passengers seating from rear. Window seating only.	Rear limit based on this case.	No problem.
Partially full one class aircraft; passengers seating from front. Window seating only.	Forward limit based on this case.	No problem.

Conclusions

Aviation has always depended for its progress on far thinking and technically adventurous people. In the Caravelle, Sud Aviation took a number of bold decisions, and in the same way as Vickers with the Viscount, pioneered a new era in air transport. The maximum benefit to the air-transport industry—manufacturer, airline and passenger—will progressively develop from these bold decisions, as more and more manufacturers and airlines add their weight and their support to the rear-engine concept. Those concerned with new procurement for the airlines know already of the crop of projects with which they are bombarded, which rely on this arrangement.

By 1965, the traveling public will be able to fly in the '*new look*' in aviation, across the Atlantic, across the Pacific, in Europe, in America, and around the world if they wish.

In this paper no attempt has been made to capitalize on the resulting passenger demand for '*the latest and the bestest.*' However, the straightforward design, engineering and operational facts set down in the paper make it difficult for any knowledgeable engineer to deny that satisfaction of the inevitable passenger demand will, in fact, benefit the airline engineer all along the line. It is up to the aircraft designer to see that neither is disappointed.

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Project Score

(Continued from page 39)

A multicoupler was placed between a 108-mc. converter and two R-390A/URR narrow-band communication receivers, thus permitting tracking on two frequencies, simultaneously.

The control unit generated the tones which commanded the satellite to either receive, transmit, or relay. Furthermore, the unit did the required sequential switching, thereby making the operation of the ground station almost automatic. A patch panel was provided at the operating position for input and output circuits, thus permitting any type of operation.

Rack mounted, remote control equipment was provided for orienting the antenna.

Four AN/FGC-25 teletype sets with four-page printers, three typing reperforators and eight transmitter distributors were used to handle seven channels of teletype. Four channels were copied on page printers and three on punched paper tape. For transmission, four transmitter distributors were used in conjunction with the AN/FGC-25's and three additional units.

How to Control
TIME, FREQUENCY and SPACE

A radio-guidance system, built by Space Technology Laboratories, Inc., played an important role in the successful launching of Pioneer V. This new ground-controlled guidance system, based on doppler-shift techniques, obtains and uses velocity and position data to control the missile.

The system relies on an accurately-controlled, stable, primary frequency — instability, f-m noise, or harmonic interference in the primary frequency could impair system performance. The G-R 1112-A Standard-Frequency Multiplier was picked by STL to help generate this frequency. It serves in an important in-line role as an element of the frequency synthesizer for this radio-guidance system. STL also uses the Frequency Multiplier in its world-wide network of tracking stations.

Telemetering, missile tracking, spectroscopy and atomic-resonance investigations, radar, and navigation-systems applications are but a few of the other areas where the 1112-A and its companion frequency multiplier, the 1112-B, find use.

U.S. Sun Orbiter Right on Beam

WASHINGTON, March 12 (AP) — Pioneer V hurtled through space today toward its destined place as a tiny new sister planet between earth and Venus in a giant orbit about the sun.

Good Operation

Pioneer V was speeding away at 6,487 m.p.h. This carried it to an estimated 213,140 miles out from earth at noon.

All equipment was reported operating perfectly. Giant radios, triggered from earth approximately once an hour, sent back loud and clear signals from which scientists computed speeds and distances.

Later today the instru- packed space · vehicle unge into its giant five- orbit around the sun. t orbit will be a 514,- 00-mile circle through between the orbits of earth and the planet s.

the orbit Pioneer V will oach to about 74,967,000 of the sun, compared the approx

Type 1112-A Standard-Frequency Multiplier . . . $1450

1-Mc, 10-Mc, and 100-Mc output frequencies are generated by separate crystal oscillators that are phase locked to the input frequency to insure extremely low f-m noise levels.

INPUT: 1-volt, 100-kc sine wave from G-R 1100-A Frequency Standard or equivalent. Can be driven by 1-Mc, 2.5-Mc, or 5-Mc standard frequency as well.

OUTPUT: 1-Mc, 10-Mc, and 100-Mc sine-wave signals; output level of each independently adjustable with maximum of 20 mw into 50 ohms.

STABILITY: Long-term stability dependent only upon driving source.

F-M NOISE: Less than 1 part in 10^9.

Type 1112-B Standard-Frequency Multiplier . . . $1360

1000-Mc output is generated directly by a klystron oscillator that is phase-locked to the 100-Mc input. Phase stability of the output is comparable to that of the input signal.

INPUT: 20-mw, 100-Mc sine wave from 1112-A or equivalent.

OUTPUT: 1000-Mc sine wave; at least 50 mw into a 50-ohm load.

STABILITY and F-M NOISE: Same as 1112-A.

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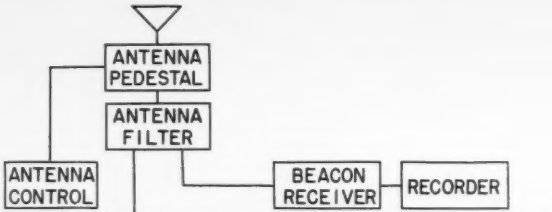

Fig. 7. Block diagram of ground system.

The last or eighth transmitter distributor was used when single channel teletype was transmitted.

A commercial voice frequency FDM terminal multiplexer was used for the seven channels of teletype.

Terminal equipment used for backup, single channel teletype included a modified AN/FGC-1 and a wideband (850 cps) audio frequency shift keyer. This equipment assured at least single channel teletype if the wow and flutter of the tape recorder in the satellite and/or signal to noise did not permit seven channel teletype.

The fade filter used was a three channel electronic switch coupled to the receiver output and a dual channel magnetic tape recorder. The received signal was sensed, and one of the following was indicated: (1) operation is normal, (2) signal from ground to satellite failed, or (3) signal from satellite to ground failed.

Temperature of the satellite was telemetered on the 108-mc. beacon carrier, amplitude modulation was used. The received modulated frequency was displayed on an electronic counter. WWV and a secondary frequency standard were used to check the operating frequency.

Both magnetic and pen recorders were installed to provide a permanent record of all pertinent data.

On one channel of the dual channel magnetic tape recorder, transmissions from the satellite were recorded; on the other channel, time and operator commands were recorded.

The dual channel pen recorder recorded AVC voltage and a reference time signal.

Power was supplied by one of a pair of 15-kw, 3-phase, 208-volt diesel-engine-driven generators.

A circularly polarized ground antenna system was desired because of the approximate omnidirectional transmission from the satellite. A phased array for four helix antennas—with about 9 db. gain at 108 mc., 14 db. at 130 mc., and 16 db. at 150 mc. with reference to over isotropic—were used. The antenna system could be oriented semiautomatic, in both azimuth and elevation, from an operating position in communication site shelter by means of a servoloop which controlled a modified searchlight pedestal. Sensing of received signal level indicated when the antenna was pointed in the correct direction. A filter separated the 108 mc. from the other two frequencies.

Fig. 7 is a block diagram of the communication system in the sites.

The communication sites were mobile, the vehicles consisting of a maintenance truck, power units, and a 26-ft. semitrailer for the main communication system.

Environmental Conditions

To determine the temperature of a satellite, one must account for the thermal radiation properties of the surface and the amount of internally dissipated power. The orbit determines the total time the satellite is in the shadow of the earth, which also effects its temperature. Incoming radiation is determined by absorptivity and the direct and reflected radiation, while the outgoing radiation is determined by emissivity and temperature of the vehicle's surface. The incoming and outgoing radiation is balanced by the absorptivity and emissivity in the visible and infrared region of the spectrum. Fig. 8 is a curve of the predicted temperature of the satellite.

To establish the proper absorptivity to emissivity ratio, the pod cover was made of magnesium with an iridite coating.

The equipment was housed in cannisters, which were mounted on fiberglass-form mounts, which kept the missile's skin thermally isolated from the equipment.

The equipment was designed to withstand a vibration of from 5 to 2,000 cps, an acceleration of 10g from 20 to 2,000 cps, and an excursion of 1/4 in. from 5 to 20 cps. All the electronics were coated with a conformal resin, and the major assemblies were encased in isocyanate foam to meet the above conditions.

Conclusion

In the near future, communication systems utilizing satellites will be operational, and through their use, communication range in the very high, ultra-high, and super-high frequency will be extended from less than a hundred miles to thousands of miles.

In the transmission of large volume, low priority traffic, a delayed repeater system employing low altitude satellites will provide an essential service. Project Score represents the first experimental demonstration of such a communication system.

Fig. 8. Predicted temperature versus time for satellite.

Parametric Weight Study

(Continued from page 49)

(limiting maximum reference temperature) is chosen as a ground rule for designing radiation-cooled vehicles.

Fig. 21 shows that the gross weight of radiation plus ablation cooled lunar vehicles increases rapidly with L/D, with the slope of the curve becoming very steep as W/S decreases. These curves reflect the shape of the corresponding structural weight ratio curves on Fig. 18.

Conclusion

The approach to weight estimation developed during this study is believed to be readily adaptable to any ground rules regarding materials, method of cooling, mission, and vehicle configuration. The results of this study, in particular the radiation-cooled lunar vehicles, are based on assumed development of exotic materials, oxidation-protection coatings, and insulation requirements that are not developed to a point where hardware may be produced today. These results are most useful for the purpose for which they were intended—to show a comparison or trend between different vehicles and heat-protection schemes. Weight comparisons of the possible combinations of L/D, mission, and type of structural cooling are a prominent part of the total configuration investigation results since, other factors being equal, lightest weight is the criterion of excellence.

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Acoustics, Sound, Noise

Acoustical Signal Detection in Turbulent Airflow. M. W. Smith and R. F. Lambert. *ASA J.*, July, 1960, pp. 858–866. Investigation of possible improvement in detected signal-to-noise ratio for a periodic signal masked by additive noise and turbulent noise backgrounds. Comparisons are made between autocorrelation, crosscorrelation, and a combination of frequency filtering and crosscorrelation. Although the latter method provided the greatest improvement, the crosscorrelation technique was the most successful single method.

Elastomers Increase Acoustic Fatigue Life. E. W. Thrall, Jr. (*SAE Natl. Aero. Meeting, New York, Apr. 5–8, 1960, Preprint 164A.*) *SAE J.*, July, 1960, pp. 52–55. Abridged.

Aerodynamics, Fluid Mechanics

Aerothermochemistry, Dissociation, Ablation

The Melting of Finite Slabs. T. R. Goodman and J. J. Shea. (*ASME West Coast Conf., Stanford, Sept. 9–11, 1959, Paper 59–AFMW-11.*) *ASME Trans., Ser. E-AM*, Mar., 1960, pp. 16–24. USAF-supported presentation of a method, based on the heat-balance integral approach, for determining the melting rate of a finite slab which is initially at a uniform temperature below the melting point.

Aerothermodynamics

The Effect of Thermal Radiation on the Inviscid Hypersonic Flow Over a Blunt Body. G. A. Bird. *J. Aerospace Sci.*, Sept., 1960, pp. 713, 714. Evaluation of the order of magnitude of a parameter useful for assessing the importance of the radiant heat loss, namely, the ratio Φ of the heat lost by an element of gas near the surface between the stagnation point and the sonic point to the change in enthalpy of the element, due to the acceleration of gas over this interval.

Heat Flux Distribution Over Hemispherical-Nosed Bodies in Hypersonic Flight. C. G. Smith. *Am. Mach. & Foundry Co. Mech. Res. Div., Paper*, 1959. 12 pp. USAF-supported extension of the results of Kemp, Rose, and Detra in closed form for the case of a hemisphere-cylinder and analysis of the Mach number dependence.

An Experimental Investigation of the Effect of Ejecting a Coolant Gas at the Nose of a Bluff Body. C. H. E. Warren. (*GALCIT HRP Memo. 47*, Dec. 15, 1958.) *J. Fluid Mech.*, July, 1960, pp. 400–417. Army-supported research.

Laminar Transfer from Isothermal Spanwise Strips on a Flat Plate. H. H. Sogin. (*ASME-AIChE Heat Transfer Conf., Storrs, Conn., Aug. 9–12, 1959, Paper 59–HT-1.*) *ASME Trans., Ser. C - HT*, Feb., 1960, pp. 53–63. 14 refs. USAF-supported investigation using the Rubesin-Klein-Tribus method to calculate rates of heat transfer by forced convection from two isothermal spanwise strips in tandem. The general results are applicable to either laminar or turbulent flow. Predictions of laminar transfer are based on Eckert's step function. The theoretical and experimental results are found to be in good agreement.

The Influence of Free Stream Turbulence on the Local Heat Transfer from Cylinders. R. A. Seban. (*ASME-AIChE Heat Transfer Conf., Storrs, Conn., Aug. 9–12, 1959, Paper 59–HT-3.*) *ASME Trans., Ser. C - HT*, May, 1960, pp. 101–107. USAF-sponsored presentation of local heat-transfer coefficients and recovery factors for three different cylinders in a two-dimensional subsonic air flow, with emphasis on the effect of screen-produced turbulence on these quantities.

Mass Transfer and Shock Generated Vorticity. H. Hoshizaki. (*Lockheed Aircraft Missiles & Space Div. TN LMSD-49721; TN LMSD-288075*, May 22; Nov., 1959.) *ARS J.*, July, 1959, pp. 628–634. 14 refs.

Heat Transfer from Transverse and Yawed Cylinders in Continuum, Slip, and Free Molecule Air Flows. L. V. Baldwin, V. A. Sandborn, and J. C. Laurence. (*ASME Papers 58–A-202, 59–HT-5.*) *ASME Trans., Ser. C - HT*, May, 1960, pp. 77–86. 34 refs. Presentation of a general Nusselt number correlation for transverse cylinders in subsonic and supersonic air flows where dissociation is negligible. New and existing data in the following experimental range have been correlated: Mach $M = 0.001$ to 6.0, Reynolds $N_{Re} = 0.02$ to 300,000, Knudsen $N_{Kn} = 4 \times 10^{-6}$ to 37.

Raschet Nagreva Dvukhsloinykh Plastin. V. I. Figurovskii. *MVO SSSR VUZ Izv. Av. Tekh.*, No. 2, 1960, pp. 99–104. In Russian. Calculation of the heating of plates composed of one layer with low thermal conductivity (insulation) and one metal layer. The temperature of the air surrounding the insulating layer is given and it is assumed that there is no heat transfer over the free surface of the metal layer. The similarity of the problem with that of airfoil heating is pointed out.

General Research in Flight Sciences—Fluid Mechanics. I—Shock-Tube Experiments Simulating Entry Into Planetary Atmospheres. R. W. Rutowski and K. K. Chan. (*AAS Western Natl. Meeting, Los Angeles, Aug. 4, 5, 1959, Preprint 59-26.*) *Lockheed Aircraft Missiles & Space Div., vol. I, Pt. II, TR LMSD-288139*, Jan., 1959–Jan., 1960. 27 pp. Presentation of preliminary results of stagnation point heat-transfer rates measured in hypervelocity flows of gas mixtures simulating the atmospheres of Venus and Mars. These measured rates are used to infer heating rates that vehicles would be expected to experience during a ballistic entry.

General Research in Flight Sciences—Fluid Mechanics. II—A Note Regarding Stagnation-Point Radiation Heat Transfer. R. W. Rutowski. *Lockheed Aircraft Missiles & Space Div., vol. I, Pt. II, TR LMSD-288139*, Jan., 1959–Jan., 1960. 11 pp. Discussion of the significance of radiation in the measurement of heat-transfer rates in partially ionized gases. It appears that heat-transfer rates can be satisfactorily represented by the use of predicted radiation and convection heat-transfer rates.

General Research in Flight Sciences—Fluid Mechanics. V—The Effect of Shock-Generated Vorticity, Surface Slip, and Temperature Jump on Stagnation-Point Heat Transfer. H. Hoshizaki. (*J. Aero/Space Sci.*, Feb., 1960, pp. 135, 136.) *Lockheed Aircraft Missiles & Space Div., vol. I, Pt. I, TR LMSD-288139*, Jan., 1959–Jan., 1960. 11 pp. Presentation of numerical solutions to the incompressible Navier-Stokes equations for the shock layer in the vicinity of the stagnation point. The normal shock relations are used as the boundary conditions, while the slip boundary conditions are used at the surface. The numerical solutions show that for an insulated body, surface slip and temperature jump reduce the heat ratio by a substantial amount.

Boundary Layer

Optimal Coordinates for a Simple Shear Flow Over a Flat Plate. Kuo-Tai Yen. (*Rensselaer Polytech. Inst. Dept. Aero. Eng. TR AE5805*, Apr., 1958.) *ZAMP*, May 25, 1960, pp. 228–236. USAF-supported study.

Boundary Layer Transition Measurements at Mach Numbers from 5.4 to 7.4. Fred Landis, M. R. Fink, and M. H. Rosenberg. *J. Aerospace Sci.*, Sept., 1960, pp. 719, 720. Presentation of the results of an investigation conducted in a continuous-flow tunnel on smooth, two-dimensional, essentially flat plate models at Mach 5.4 to 7.4 and Reynolds numbers of 0.2×10^6/in. to 0.6×10^6/in. The test results show that the transition Reynolds number increases with increasing Mach number at Mach numbers above 5, that the transition Reynolds number increases with increasing Reynolds number, and that small favorable pressure gradients upstream of the transition location do not appear to alter the transition location significantly at hypersonic speeds.

A Particular Solution to the Turbulent-Boundary-Layer Equations. G. K. Walker. *J. Aerospace Sci.*, Sept., 1960, pp. 715, 716. Presentation of an analysis extending the turbulent, compressible, zero-pressure-gradient boundary-layer relations to include the case of a blunt body with a finite pressure gradient, and arriving at a simpler solution by replacing the assumptions of unit Prandtl number and Reynolds analogy by a single relation.

On the Three-Dimensional Turbulent Boundary Layer Generated by Secondary Flow. J. P. Johnston. (*ASME Hydraulic Conf., Ann Arbor, Apr. 13–15, 1959, Paper 59–Hyd-6.*) *ASME Trans., Ser. D - BE*, Mar., 1960, pp. 233–246; Discussion, pp. 246–248. 14 refs. Presentation of a study of the secondary flow type of three-dimensional turbulent boundary layer. A mathematical model of the relationship between the cross-flow and main-flow components of the velocity vectors of the layer is established. By means of this model, some of the relationships required to carry out a boundary-layer problem solution by the use of the momentum-integral equations are developed.

Conical Turbulent Boundary Layer Experiments and a Correlation with Flat Plate Data. W. S. Bradfield. (*ASME-AIChE Heat Transfer Conf., Storrs, Conn., Aug 9–12, 1959, Paper 59–HT-6.*) *ASME Trans., Ser. C - HT*, May, 1960, pp. 94–100. 18 refs. Presentation of the first measurements of total temperature profiles, directly determined skin friction, and local heat flux in the turbulent boundary layer of unyawed cone models for Mach numbers from 1 to 6. These experimental data are shown to justify the calculation of turbulent friction and heat transfer on unyawed cones by means of an incompressible plate friction law and simple auxiliary relations.

Flow of Fluids

Some Real-Gas Flow Parameters for Air. W. D. Erickson. *J. Aerospace Sci.*, Sept., 1960, pp. 716, 717. Discussion of three flow ratios: (a) free-stream static temperature to stagnation temperature, (b) free-stream static pressure to stagnation pressure, and (c) total pressure behind a normal shock to stagnation pressure. The method of finding the three flow-parameter ratios is illustrated by a numerical example.

Oscillations in a Plasma in a Weak Magnetic Field. Kiyoe Kato. *Phys. Soc. Japan J.*, June, 1960, pp. 1093–1100. 10 refs. Study presenting two types of oscillations, the cyclotron resonance oscillation whose frequency depends on the magnetic field strength alone, and the plasma type oscillation whose frequency depends on the electron concentration as well as the magnetic field strength.

Flow Between Torsionally Oscillating Disks. S. Rosenblat. *J. Fluid Mech.*, July, 1960, pp. 388–399. Analysis concerning two parallel infinite discs torsionally oscillating about a common axis and immersed in a viscous fluid. Two cases are considered: (1) one disc only is in motion and (2) the discs oscillate 180° out of phase, but with the same frequency and amplitude.

Taylor Instability in Shock Acceleration of Compressible Fluids. R. D. Richtmyer. *Commun. on Pure & Appl. Math.*, May, 1960, pp. 297–319. Analysis of the growth of irregularities when a shock sweeps across a corrugated interface from a less dense to a more dense fluid. Pressure perturbations and the motion of the interface are computed.

Effect of the Wall on Two-Phase Turbulent Motion. S. L. Soo and C. L. Tien. (*ASME West Coast Conf., Stanford, Sept. 9–11, 1959, Paper 59–APMW-18.*) *ASME Trans., Ser. E - AM*, Mar., 1960, pp. 5–15. 12 refs. Presentation of an analysis yielding the stationary solution on the effect of a wall on two-phase (solid particles in gas) turbulent motion showing that the intensity of motion of solid particles is affected by the presence of the wall and the distribution of turbulent intensity of the stream near the wall.

K Voprosu o Turbulentnom Techenii Zhidkosti. Ia. L. Fogel'. *MVO SSSR VUZ Izv. Av. Tekh.*, No. 2, 1960, pp. 105–109. In Russian. Presentation of a method for calculating turbulent flows on the basis of empirical relationship between the forces of apparent viscosity, due to the turbulent mixing and time-averaged velocities. A comparison between theoretical and experimental results shows that the friction due to molecular motion is greatly decreased during the transition from laminar to turbulent region, and that the remaining friction is due to flow pulsations.

Interference Effects Due to Vortex Sheets According to Slender Body Theory. A. von Baranoff. (*La Recherche Aéronautique*, Jan.–Feb., 1959, pp. 3–11.) *Gt. Brit., RAE Lib. Transl. 892*, Apr., 1960. 19 pp. Presentation of generalized formulas for the forces and moments exerted on the rear part of a missile by vortex sheets formed at a wing, derived by means of the slender body theory. Examples illustrate the application of these formulas.

Internal Flow

Induced Velocities in the Two-Dimensional Cascade Theory. J. Polášek. *ASME Trans., Ser. E - AM*, June, 1960, pp. 355, 356. Presentation of a simplification in Schilhansl's approximate method for calculating the velocity component induced on a section of a two-dimensional cascade by vortices distributed on the remaining sections. It is shown that relatively simple expressions for the exact calculation can be obtained by the use of the function of complex variable.

Crossover Systems Between the Stages of Centrifugal Compressors. G. O. Ellis. (*ASME Hydraulic Conf., Ann Arbor, Apr. 13–15, 1959, Paper 59–Hyd-3.*) *ASME Trans., Ser. D - BE*, Mar., 1960, pp. 155–167; Discussion, R. C. Dean, Jr., and W. A. McGahan, pp. 167, 168; Author's Closure, p. 168. Presentation of a design procedure determining the location and orientation of vanes in an annulus on the basis of two principles derived in a discussion of simple elbows. To test the proposed design, a low-speed model was built and tested, and the results compared with a second model which represented a more conventional design.

Neodnoznachnost' Resheniia Zadachi o Forme Potoka v Osevoi Turbomashine. V. N. Ershov. *MVO SSSR VUZ Izv. Av. Tekh.*, No. 2, 1960, pp. 80–87. In Russian. Evaluation of solutions for the problem of determining the shape of flow in axial turbomachines.

Separation Prediction for Conical Diffusers. J. M. Robertson and H. R. Fraser. (*ASME Hydraulic Conf., Ann Arbor, Apr. 13–15, 1959, Paper 59–Hyd-14.*) *ASME Trans., Ser. D - BE*, Mar., 1960, pp. 201–207; Discussion, pp. 207, 208; Authors' Closure, pp. 208, 209. 15 refs. Presentation of a method of incompressible turbulent boundary-layer analysis based on the D parameter introduced by Ross, as applied to conical-diffuser flow. The separation conditions are shown to depend on the initial momentum-thickness Reynolds number and a distance parameter involving the initial momentum thickness, the initial radius, and the diffuser length. Comparison with experimental information on diffuser separation indicates that the predictions are reliable, but conservative.

Pressure Drop and Heat Transfer in a Duct with Triangular Cross Section. E. R. G. Eckert and T. F. Irvine, Jr. (*ASME-AIChE Heat Transfer Conf., Storrs, Conn., Aug. 9–12, 1959, Paper 59–HT-10.*) *ASME Trans., Ser.*

C - HT, May, 1960, pp. 125–136; Discussion, pp. 136–138. 12 refs. Presentation of friction factors measured for a duct whose cross section has the shape of an isosceles triangle with a side ratio 5 to 1 in the fully developed flow region for laminar, transitional, and turbulent conditions. In addition, local and average heat-transfer coefficients and the temperature field in the duct wall have been determined for the condition of constant heat generation per unit volume of the duct walls.

Evaluation of Bulk Velocity and Temperature for Turbulent Flow in Tubes. G. F. C. Rogers and Y. R. Mayhew. *Internatl. J. Heat & Mass Transfer*, June, 1960, pp. 55–67. Presentation of two methods to obtain the bulk velocities and temperature, without resorting to traversing or the use of mixing chambers. In the axial method, the velocity or temperature probe is placed at the axis, and the reading multiplied by an appropriate weighting factor. The y_m/r method places the probe at a distance from the wall at which it reads the mean value directly.

A Shock-Tube Technique to Determine Steady-Flow Losses of Orifices and Other Duct Elements. George Rudinger. (*ASME Hydraulic Conf., Ann Arbor, Apr. 13–15, 1959, Paper 59-Hyd-13.*) *ASME Trans., Ser. D - BE*, Mar., 1960, pp. 195–200. 16 refs. Navy-supported investigation showing that a simple shock tube is capable of producing appreciable steady-flow rates through a short duct element, such as an orifice, a valve, or a screen. The flow upstream and downstream of the test element and, therefore, also the losses caused by the test element, can be calculated from known initial conditions in the shock tube and pressure measurements at one point upstream of the element. Experiments to determine the discharge coefficient of a sharp-edged orifice are described as an illustration of the method. The results are in good agreement with available steady-flow data.

Über die Trennung von Gasgemischen in laminarer Strömung. Janez Strnad. *ZAMP*, May 25, 1960, pp. 245, 246. In German. Analysis of the separation effect in a gas mixture flowing laminarly and hydrodynamically through a cylindrical pipe with constant wall temperature.

Riemann's Problem for a Laval-Nozzle. I—Hydraulic Approximation. Rudolf Schatz. *Munich Tech. Hochsch. Math. Inst. TN 9* (*AFOSR TN 59-709*), Aug. 12, 1959. 23 pp. Application of the hydraulic approximation to the solution of Riemann's problem concerning the flow field arising from a discontinuous initial distribution of pressure, density, and entropy. In addition to the physical interpretation of the results, a detailed analysis of the stability and the convergence of the difference methods employed is incorporated.

Ejector-Nozzle Flow and Thrust. Appendix I—**Thrust Coefficient of the Ejector Nozzle.** Appendix II—**Mixing of Primary and Secondary Streams in an Ejector Nozzle.** H. E. Weber. (*ASME Hydraulic Conf., Ann Arbor, Apr. 13–15, 1959, Paper 59-Hyd-5.*) *ASME Trans., Ser. D - BE*, Mar., 1960, pp. 120–129; Discussion, J. Fabri and E. Le Grives, pp. 129, 130; Author's Closure, p. 130. Presentation of an analysis for predicting the secondary and primary flows and the thrust coefficient of ejector nozzles. Particular attention is given to the diverging shroud ejector in which the throat of the secondary stream is formed at a small distance downstream of the primary nozzle exit—i.e., near the plane of the minimum shroud area.

Condensation Shocks in Supersonic Nozzles. A. A. Stepchkov. (*MVO SSSR VUZ Izv. Av. Tekh.*, Apr.–June, 1959, pp. 119–129.) *ARS J. Suppl.*, July, 1960, pp. 695–699. Translation. Application of the known equations of thermodynamics to determine the beginning of saturation, considered as the onset of condensation. The dependence of saturation pressure from the variation of external conditions is determined from the equilibrium of the two phase system on the basis of the Clapeyron-Clausius equation.

Performance

Graphic Presentation of Optimum Flight Profiles. D. W. Richardson. *Aerospace Engrg.*, Sept., 1960, pp. 16, 17, 46. Discussion of the visual display of optimum flight profiles for interceptor aircraft, determined by the technique of dynamic programing. A ground-based computer (IBM 709) program is studied which outputs a printed graphical presentation of the families of optimum flight profiles and performs functions involving the problems of selecting general flight control laws and logic to be designed into airborne flight computers. Typical tactical situations are presented and analyzed.

Stability & Control

A New Modified Acceptance Criterion for Lateral-Directional Flying Qualities. R. M. Crone and R. C. A'Harrah. (*IAS 28th Annual Meeting, New York, Jan. 25–27, 1960, Paper 60-18.*) *Aerospace Engrg.*, Sept., 1960, pp. 24–29. 14 refs. Presentation of a criterion for the specification of satisfactory lateral handling qualities on the basis of a parameter which successfully correlates pilot opinion rating of the lateral handling qualities.

Wings & Airfoils

On the Nonstationary Motion of a Wing with Rectangular Planform. V. A. Kovaleva. (*Prikl. Mat. i Mekh.*, Nov.-Dec., 1959, pp. 1030–1041.) *PMM—Appl. Math. & Mech.*, No. 6, 1959, pp. 1476–1491. Translation. Investigation of the unsteady motion of a thin wing of finite aspect ratio in supersonic flow of arbitrary velocity variation, which includes the passage through a gust or a shock front. The problem is linearized. The solution of the problem is found for the case of a change in wing angle of attack, and the obtained solution is used to examine cases where the angle of attack of the wing changes arbitrarily with time.

Hilfsmittel für die Sicherheit in der heutigen Flugtechnik. Wolfgang Liebe. *VDI Zeitschrift*, June 11, 1960, pp. 681–684. In German. Discussion of the devices used for landing speed reduction which provide additional safety installing flight. Included are leading-edge flaps and stringer strips, boundary-layer fences, sawtooth leading edges, beak noses, and vortex generators.

Sur l'Eclatement des Tourbillons d'Apex d'une Aile Delta aux Faibles Vitesses. H. Werlé. *La Recherche Aéronautique*, Jan-Feb., 1960, pp. 23–30. In French. Presentation of experimental results obtained on the breaking-up of vortices under the effect of turbulence. Visualization tests made in a hydrodynamic tunnel are described in detail

Theoretical and Experimental Investigation of Second-Order Supersonic Wing-Body Interference. Marten Landahl, George Drougge, and Beverly Beane. (*IAS Natl. Summer Meeting, Los Angeles, June 16–19, 1959, Paper 59-117.*) *J. Aerospace Sci.*, Sept., 1960. pp. 694–702. USAF-sponsored research.

Aeroelasticity

Panel Flutter and Divergence Criteria; Design Guide for Flat Unbuckled Sheets. D. J. Johns. *Aircraft Eng.*, July, 1960, pp. 203, 204. Presentation of data in graphical form for pin-jointed panels on many supports, pin-jointed single panels, and encastre single panels.

Emploi de la Méthode Vectorielle d'Analyse dans les Essais de Vibration. G. de Vries. *La Recherche Aéronautique*, Jan.-Feb., 1960, pp. 41–47. In French. Description of the method of vector analysis used in vibration tests.

Steady-State Undamped Vibrations of a Class of Nonlinear Discrete Systems. P. R. Sethna. (*ASME Annual Meeting, Atlantic City, Nov. 29–Dec. 4, 1959, Paper 59-A-67.*) *ASME Trans., Ser. E - AM*, Mar., 1960, pp. 187–195. 10 refs. Study of steady-state vibrations of a class of nonlinear discrete systems with an arbitrary number of degrees of freedom. A perturbation scheme is used to obtain the solutions. Some special effects of the ratios of the linear natural frequencies on the qualitative nature of the solutions are demonstrated. Solutions are obtained for some specific problems, and the results are checked against those obtained from an analog-type computer.

Free Vibrations of Lightly Damped Systems by Perturbation Methods. P. Lancaster. *Quart. J. Mech. & Appl. Math.*, May, 1960, pp. 138–155. Development of a method by means of small perturbation theory for the estimation of frequencies, rates of decay, and modes of vibration of the system when small damping forces are introduced.

New Design Techniques for Damping Structural Resonances. J. E. Ruzicka. *Barry Controls Paper*, 1960. 55 pp. 21 refs. Presentation of the disadvantages of some design practices, of methods for specifying structural damping, and of the damping properties of engineering materials. Highly damped structural designs using viscoelastic damping materials are studied.

Vibrations and Waves in Elastic Bars of Rectangular Cross Section. R. D. Mindlin and E. A. Fox. (*ASME West Coast Conf., Stanford, Sept. 9–11, 1959, Paper 59-APMW-23.*) *ASME Trans., Ser. E - AM*, Mar., 1960, pp. 152–158. Navy-supported presentation of an exact solution of the equations of elasticity for a family of modes of vibration, or waves, in an infinite bar of rectangular cross section for certain ratios of width to depth. The solution is composed of coupled dilatational and equivoluminal waves, and the four faces of the bar are free of traction.

Aeronautics, General

Special Issue: 42nd Annual Statistical Issue & Marketing Guide. *Auto. Ind.*, Mar. 15, 1960. 378 pp. Detailed directory of manufacturers including aircraft and parts, engines, and propellers, as well as scheduled airlines, aircraft registrations, and other specifications.

Special Issue: Missile Market and Product Guide Edition. *Missiles & Rockets*, May 30, 1960, pp. 83–359. Alphabetical listing of almost 5,000 companies engaged in the missile industry, and 3,200 parts and products used by the industry, with a list of manufacturers of these items appearing under each product.

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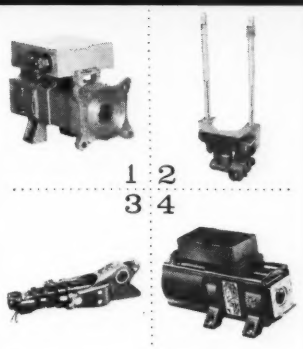

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Air Transportation

Efficiency Criterion for Comparing Cargo Aircraft in Deliveries Between Two Terminals. R. P. Brady and J. E. Walsh. *Oper. Res.*, May-June, 1960, pp. 356–361. 11 refs. Study of the more important factors which influence the ability of a given cargo aircraft and cargo-handling system combination to perform a specified task. A quantitative criterion is presented for measuring the relative efficiency of combined air-cargo systems of this type.

Mechanical Loading for the CL-44; 65 Minute Turnarounds Possible with New Cargo Handling System. *Aircraft* (Canada), July, 1960, pp. 30, 32. Presentation of a new cargo handling system which makes possible 65 min. turnarounds of the transport aircraft.

Airplanes

Description

The Argosy Air Freighter. J. H. Stevens. *Aircraft* (Canada), July, 1960, pp. 24, 25, 27, 29, 59, 60. Presentation of the design, performance capability, and engine data of the Argosy.

Avro-748—Feeder-Line Transport. *The Aeroplane & Astronautics*, July 8, 1960, pp. 39–46, cutaway drawing. Survey of the design, performance, power-plant, and system's characteristics of a turboprop aircraft.

Inside the IL-18. *Flight*, July 1, 1960, pp. 13–17, cutaway drawing. Presentation of design, performance, and system's characteristics of the Soviet turboprop aircraft Ilyushin IL-18.

Les Tendances Modernes des Avions Commerciaux. I. H. J. Alter. *L'Air*, Jan., 1960, pp. 12–15. In French. Survey of current trends in the construction of commercial aircraft as affected by the use of turbojet engines, aerodynamic aspects of high-speed flight, and economic considerations.

Les Tendances Modernes des Avions Commerciaux. II. H. J. Alter. *L'Air*, Feb., 1960, pp. 10–12. In French. Further survey of current trends in the construction of modern commercial aircraft, covering structural, propulsion, and maintenance problems.

Un Nouvel Avion de Transport Français—Le Quadriturbopropulseur Potez 840. *L'Air*, Mar., 1960, p. 33. In French. Description of the French four-engine turboprop Potez 840, covering details of the power plants, structure, landing gear, and performance.

Military Aircraft of the World—1960. *Flight*, July 8, 1960, pp. 43–74. Survey of military aircraft types covering the design characteristics, armament, and dimensions, as well as the development history.

Aspects Multiples de l'Elaboration Technique d'un Avion Moderne—La Caravelle. P. Satre. *Tech. & Sci. Aéronautiques*, Nov.-Dec., 1959, pp. 343–362; Discussions, pp. 363, 364. In French. Discussion covering various aspects of the development of Caravelle, including aerodynamic, design, and structural considerations. The equipment and installation of various systems are described, and details are given of static, fatigue, noise fatigue, vibration, and flight tests.

Nuclear Aircraft Attain Best Productivity with Turboprop Engine; Cruise Speed of 0.55 Mach Number; Low Cruise Altitude. D. P. Lalor and W. C. Schmill. (*SAE Natl. Aero. Meeting, New York, Apr. 5–8, 1960, Preprint 167B.*) *SAE J.*, July, 1960, pp. 46, 47. Abridged.

Über die neuzeitliche Verkehrsflugzeug-Entwicklung. Hans Wocke. *VDI Zeitschrift*, June, 1960, pp. 713–722. In German. Discussion of the present trend from piston engines toward pure jet turbines. The different models are discussed according to their intended function, economic performance, and operating costs. Comparisons of cruising speeds, weight distribution, economy, choice of power plant, wing configuration, and controls systems are made.

Supersonic Flight. H. L. Hibbard. *3rd Albert Plesman Memorial Lecture, Delft, Oct. 6, 1959, Paper.* 61 pp. Presentation of the historical highlights in the development of supersonic flight, certain aspects of the operational status of military supersonic flight, and a quantitative assessment of the technical feasibility and economic soundness of commercial air transport in the supersonic range.

Studies in Design; An Analysis of Recent Projects at the College of Aeronautics. *Flight*, July 1, 1960, pp. 19, 20. Brief description of six design projects of the following types: photographic reconnaissance aircraft; research aircraft; transatlantic airliner; tactical strike bomber; heavy, general-purpose freighter; and a supersonic transatlantic airliner.

Operating Characteristics, Economics

Supersonic Transports; Operational Factors, Financial Considerations and National Policy. *Soc. Exp. Test Pilots Quart. Rev.*, Spring, 1960, pp. 26–45. Presentation of the history of jet aircraft and discussion of the following problem areas: engine noise during afterburning take-off, cabin floor angles, sonic boom, ozone concentration at operating altitudes, and the largest aerodynamic heating load developed during cruise flight. Development costs for the different types of jet aircraft are compared, the economic feasibility of supersonic airliners is considered, and the political implications are noted.

Some Operating Features of the World's Fastest Airliner—The Convair 880. Don Germeraad. *Soc. Exp. Test Pilots Quart. Rev.*, Spring, 1960, pp. 3–11. Discussion of the flight characteristics, engines, air data computer, emergency operation, and the flight test program of the Convair 880 medium-range jet airliner.

DC-8 Structure Strength and Operating Technique. *Douglas Serv.*, Mar.-Apr., 1960, pp. 1–22. Discussion of design factors underlying the control of DC-8 loading and airspeed.

Airports

A New Major Airport for the New Jersey-New York Metropolitan Area; A Report on Preliminary Studies by the Port of New York Authority. *The Port of New York Authority, Paper*, Dec. 14, 1959. 38 pp.

The Development of a High Pressure Burner System for Fog Dispersal. James Kerr. *Gt. Brit., RAE TN Mech. Eng.* 313, Mar., 1960. 63 pp.

Apron Planning for the Jets. R. A. Twomey. *Flight*, June 24, 1960, pp. 872, 873. Presentation of the factors affecting the jet blast velocity and discussion of acceptable blast levels. It is found that the apron slope affects the breakaway blast, and that the most efficient apron layout for the short-haul operator is the pier system.

Aviation & Space Medicine

Medical Considerations in Civil Jet Operations. O. B. Schreuder. *Aerospace Med.*, July, 1960, pp. 578–583. 10 refs. Review of the more important problems in civil jet operations, including the effects of a loss of pressurization, on aircrew, passengers, and ground personnel.

Basic Research Problems in Space Medicine: A Review. R. T. Clark, H. G. Clamann, Bruno Balke, P. C. Tang, J. D. Fulton, Ashton Graybiel, and J. Vogel. *Aerospace Med.*, July, 1960, pp. 553–577. 14 refs. Discussion of the physiologic and psychologic problems in space flight and of the research effort in these areas, including the subgravity state during parabolic flight and its effect on a living organism, life cells, respiratory-metabolism problems, motion sickness, physiologic instrumentation of man during flight, disorientation of pilots, photosynthetic gas exchangers and recyclers in closed ecological systems, survival of terrestrial organisms under extreme environmental conditions, and physiological aspects of training and selection for manned extra-terrestrial flights.

Space Transport of Life in the Dried or Frozen State. A. S. Parkes and A. U. Smith. (*Space Med. Symposium, London, Oct. 16, 17, 1958.*) *Brit. Interpl. Soc. J.*, May-June, 1960, pp. 319, 320. Discussion of modern biological knowledge of the resistance of living organisms to freezing, drying, and lack of oxygen, considered with respect to the conditions likely to be encountered in space and on the planets.

Some Nutritional Problems of Manned Spaceflight. M. H. Briggs. *Brit. Interpl. Soc. J.*, May-June, 1960, pp. 325–327. 13 refs. Discussion of the most suitable diet for the crew of a spaceship. Methods for the recovery of water and other substances from human excreta are reviewed and problems of algal culture from these extracts are outlined.

Some Problems of Spaceflight Feeding. S. W. F. Hanson. (*Space Med. Symposium, London, Oct. 16, 17, 1958.*) *Brit. Interpl. Soc. J.*, May-June, 1960, pp. 314–316. Discussion of feeding problems in space flights lasting several hours, several days, months, or years. Solutions are seen in special foods fed through an oxygen mask and in dehydrated foods. The feasibility of the closed man-plant cycle as a solution is questioned.

Heat Exchange Between Man and His Environment on the Surface of the Moon. J. Billingham. (*Space Med. Symposium, London, Oct. 16, 17, 1958.*) *Brit. Interpl. Soc. J.*, May-June, 1960, pp. 297–300. Presentation of an analysis of the heat exchange between man and a spacesuit, and the suit and the surroundings, at different times and places on the surface of the moon. Three methods of obtaining the required cooling of the suit are compared.

Effects of Prolonged Exposure to Positive *g* Loadings on the Pulmonary Gas Exchange. Hilding Bjurstedt. (*Space Med. Symposium, London, Oct. 16, 17, 1958.*) *Brit. Interpl. Soc. J.*, May-June, 1960, pp. 288, 289. Presentation of the results of an investigation performed on anesthetized dogs subjected to prolonged *g* forces in the head-to-tail direction. Hyperoxaemia was found in the animals in spite of the fact that they were hyperventilating and breathing 100 per cent oxygen.

Human Body as an Inconstant Heat Source and Its Relation to Determination of Clothes Insulation. I—Descriptive Models of the Heat Source. II—Experimental Investigation Into Dynamics of the Source. A. S. Iberall. (*ASME Instruments & Regulators Conf., Cleveland, Mar. 29–Apr. 2, 1959, Papers 59-IRD-7; 59-IRD-8.*) *ASME Trans., Ser. D - BE*, Mar., 1960, pp. 96–112.

Some Blast Studies with Application to Explosive Decompression. Carl-Johan Clemedson. (*Space Med. Symposium, London, Oct. 16, 17, 1958.*) *Brit. Interpl. Soc. J.*, May-June, 1960, pp. 279–285. 26 refs. Discussion of the similarities and differences in the biological effects caused by explosive decompression and by blast. It is found that the qualitative changes in respiration and circulation, and the pathological changes in the lungs are the same, but that the reflex mechanism mediating the physiological changes may differ for these two kinds of trauma.

Fatigue Effects in Radio Operators During a Program of High Intensity, Long Duration, Flying. G. M. Jones. *Aerospace Med.*, June, 1960, pp. 478–484. 11 refs. Investigation of activity in radio operators during long-duration reconnaissance flight in piston engine aircraft to determine the most appropriate way in which to distribute the load of maintaining a continuous watch. The optimum duration of watch for a signaller on radio operator duty in flight is found to be three hours.

The Physiological Effects of Transient Mechanical Forces: A Review of Their Relevance to Astronautics. J. C. Guignard. (*Space Med. Symposium, London, Oct. 16, 17, 1958.*) *Brit. Interpl. Soc. J.*, May-June, 1960, pp. 290–292. Survey of the mechanical stresses which may occur in spaceflight and of the physiological responses to these stresses.

The Effects of Sensory Impoverishment, Confinement and Sleep Deprivation. Cyril Cunningham. (*Space Med. Symposium, London, Oct. 16, 17, 1958.*) *Brit. Interpl. Soc. J.*, May-June, 1960, pp. 311–313. 15 refs. Discussion of the probable effects of conditions similar to those expected in space flight—i.e., isolation, restriction of personal movement, deprivation of auditory and external visual stimuli and sleep, and unawareness of the vehicle's movement in space. Conclusions are drawn from experimental tests of six days' maximum duration, and from the study of the experiences of persons who have spent many months in foreign isolation prisons.

A Review of Available Information on the Acoustical and Vibrational Aspects of Manned Space Flight. H. J. Jacobs. *Aerospace Med.*, June, 1960, pp. 468–477. 11 refs. Discussion of the probable acoustic environment for space capsules and of the human tolerance to noise, including permanent and temporary effects.

The Potential Application of Hibernation to Space Travel. R. J. Hock. (*Aero Med. Assoc. 30th Annual Meeting, Los Angeles, Apr. 28, 1959.*) *Aerospace Med.*, June, 1960, pp. 485–489. 17 refs. Discussion of the possibility to slow down the ageing process during long duration (several to many years) space flight by inducing a winter-sleep-like condition in man. Reduction of the body temperature with possible periodic interruptions of this hypothermic condition to prevent ventricular fibrillation and to allow certain necessary physiological processes to go on is seen as a main possibility in achieving hibernation in man.

Man's Thermal Environment During Interplanetary Travel. J. Billingham. (*Space Med. Symposium, London, Oct. 16, 17, 1958.*) *Brit. Interpl. Soc. J.*, May-June, 1960, pp. 293–297. Discussion of the factors affecting heat exchange between man and a sealed cabin. Probable values for the various parameters are assumed and calculations are made of the heat transfer under ten different conditions.

Airborne GSR Studies; A Preliminary Report. G. J. D. Shock. *Aerospace Med.*, July, 1960, pp. 543–546. Discussion of evidence gained from subjects exposed to pre-weightlessness accelerations and weightlessness which suggests that changes in GSR and heart rate are due to emotional factors rather than to weightless or positive *g*. Instrumentation techniques for high performance aircraft are presented for measuring GSR and heart rate of human subjects.

Some Consequences of Weightlessness and Artificial Weight. M. P. Lansberg. (*Space Med. Symposium, London, Oct. 16, 17, 1958.*) *Brit. Interpl. Soc. J.*, May-June, 1960, pp. 285–288. Discussion of the physiological consequences of weightlessness showing that, due to the absence of convection, artificial ventilation will be necessary, but that muscular atrophy is not a real danger although motor activities may have to be relearned. Problems raised by rotation of the space vehicle to produce artificial "weight" are also considered.

Electrographic Study of Syncopal Predisposition. H. Gastaut and C. Gibson. (*Aero Med. Assoc. 30th Annual Meeting, Los Angeles, Apr. 29, 1959.*) *Aerospace Med.*, July, 1960, pp. 531–542. 18 refs. Discussion of three tests – the ocular compression, carotid sinus compression, and the Valsalva tests – which should all be carried out on the sitting subject with simultaneous and continuous electroencephalographic, electrocardiographic, and blood pressure recording to assess the syncopal predisposition in aircraft crews.

(Continued on page 99)

INTERNATIONAL AERONAUTICAL ABSTRACTS

A Review of Worldwide Scientific and Technical Literature

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ACOUSTICS, SOUND, NOISE

EXPERIMENTAL STUDY OF THE RANDOM VIBRATIONS OF AN AIRCRAFT STRUCTURE EXCITED BY JET NOISE. B. L. Clarkson and R. D. Ford. U. Southampton Dept. Aeron. & Astron. Rep. 128, Jan., 1960. 32 pp. USAF-sponsored investigation of the strains induced in a full-scale rear fuselage test structure of the Caravelle airliner when one jet engine is running at maximum take-off thrust. Emphasis is placed on the strains in the center of panels. Correlation measurements indicate that the lower frequencies (up to 500 cps) are associated with overall vibration modes and have low strain amplitudes. The larger panel strains occur at higher frequencies with the frames acting as boundaries. In these measurements, the main resonance peak in each panel occurs at about 600-700 cps and is identified with the fundamental stringer twisting mode - i.e., adjacent panels 180° out of phase. There are generally two smaller peaks in 800-1,000 cps range but the modes of vibration are not completely identified due to lack of information.

AERODYNAMICS, FLUID MECHANICS

Aerothermochemistry, Dissociation, Ablation

PLASMA SHEATH CHARACTERISTICS ABOUT HYPERSONIC VEHICLES. H. G. Lew and V. A. Langelo. (IRE-ARS 14th Annual Spring Meeting, Cincinnati, Apr. 12, 13, 1960.) G-E MSVD SSL TIS R60SD356, Apr. 6, 1960. 40 pp. Investigation covering vehicle induced interferences to signal transmission and presentation of some results for a typical re-entry body. The shock layer of the body is investigated. The characteristics of the induced shock layer ionization for a real gas in equilibrium for the configuration is given for different flow conditions. For altitudes below about 300,000 ft. and Mach numbers to 15, the shock layer is reasonably in chemical equilibrium with ionization taking place so fast that an equilibrium composition of the gas is maintained at all points in the field. The nonequilibrium effects are discussed; in addition, effects of contamination are included. In the boundary-layer region, the temperatures are high and the fluid transport phenomena are included and, in this connection, a turbulent dissociated gas is studied for various altitudes. The flow from the shock layer passes on to the rear and forms the wake which has sufficient enthalpy to leave an ionized trail. Results are obtained which show that these wakes persist to a considerable distance behind the body and contain a high electron density. These are given for both a continuum and a rarefied gas. The attenuation of plane electromagnetic waves is obtained for the induced environment about the body. The variation of attenuation with altitude is discussed, and it is found that there is a range of altitude for any given wavelength for which the attenuation is high so that signal transmission is difficult.

A PRELIMINARY STUDY OF IONIC RECOMBINATION OF ARGON IN WIND TUNNEL NOZZLES. K. N. C. Bray and J. A. Wilson. U. Southampton Dept. Aeron. & Astron. Rep. 134, Feb., 1960. 55 pp. USAF-sponsored presentation of a theory for an ideal ionizing monatomic gas along with a Mollier chart for this gas in equilibrium. Its flow through nearly conical nozzles is considered for cases where ionic recombination is either in complete equilibrium or completely frozen. A discussion is included of conditions under which the ionization fraction becomes vanishingly small, when the gas behaves as a perfect gas. In the absence of a suitable rate equation, the quasi-one-dimensional flow equations are not integrated for partial equilibrium cases, but criteria are given for the flow to be near to equilibrium and nearly frozen. Departures from adiabatic flow due to photon emission are also considered and shown to be negligible.

TRANSIENT TEMPERATURE IN A SEMI-INFINITE, POROUS SOLID WITH PHASE CHANGE AND TRANSPIRATION EFFECTS. R. J. Grosh. USAF WADD TR 60-105, Jan., 1960. 24 pp. 12 refs. Presentation of solutions for the transient

temperature distribution in a semi-infinite solid whose interconnected pores were initially filled with a material which undergoes a phase change and, because of the resulting change in density, streams or transpires toward the accessible surface. The possibility that several phase changes can occur is considered along with variations in thermal properties from one phase to another. The solutions for the temperature distribution are given in terms of well known, tabulated functions. However, the phase front positions are determined by solving a set of nonlinear algebraic equations. The total results are of interest in developing materials for transient, high temperature environment conditions.

DAMPING OF THE SATELLITE WAKE IN THE IONOSPHERE. S. Rand. Phys. Fluids, July-Aug., 1960, pp. 588-599. 10 refs. Study of Landau damping of the ion plasma oscillations which constitute the wake of a line charge moving supersonically through a low-density plasma. Maxwellian distribution functions in the ambient plasma for both electrons and ions are assumed. It is found that the damping is critical to the question of whether the electrohydrodynamic wake produced by a satellite in the ionosphere is observable, unless the electron temperature is at least an order of magnitude greater than the ion temperature.

THE SURFACE ABLATION OF FIBER REINFORCED PLASTICS PARALLEL TO AN OXYACETYLENE FLAME. R. B. Greene. U. Calif. Inst. Eng. Res. Ser. 128/I4 TR HE-150-179, Feb. 25, 1960. 58 pp. 20 refs. Army-sponsored investigation of 12 different specimens of fiber reinforced plastics, subjected to flat plate turbulent heating from an oxyacetylene flame. Temperature histories were obtained from the surface and six thermocouples embedded within the test specimens. Surface emissivities, thermal diffusivities, weight and thickness losses to ablation, and values for the heat of ablation were calculated from the test data.

OPLAVLENIE POLUBESKONECHNOGO TELA V PLOSKOM I OSESIMMETRICHNOM POTOKE NESZHIMAEMOGO GAZA. G. A. Tirskii. AN SSSR Dokl., June 1, 1960, pp. 785-788. In Russian. Study of the ablation of a semi-infinite body in a plane and axisymmetric flow of incompressible gas. It is shown that the complete equations (Navier-Stokes equations and equations of heat addition without dissipation) with corresponding boundary conditions over the discontinuity surface allow for an exact solution representing the stationary ablation rate in the neighborhood of the critical point on the body in the semispace in the plane and axisymmetric flow of incompressible gas. In the latter case, the body can rotate with a constant angular velocity ω about the axis of the flow.

Aerothermodynamics

ESTIMATION OF THE HEAT TRANSFER FROM THE REAR OF AN IMMERSED BODY TO THE REGION OF SEPARATED FLOW. P. D. Richardson. Brown U. Div. Eng. Rep. (USAF WADD TM 59-1), Jan., 1960. 25 pp. 39 refs. Analysis considering the region of separated flow on a bluff body in a transverse stream of fluid. An approximate method is described to calculate the convective heat transfer. It is applied to a cylinder in a transverse air stream, and the results are compared with experimental data in the literature. The agreement is found to be good.

PRELIMINARY ANALYSIS OF THE CAPABILITIES OF A COMPOSITE SLAB FOR AN ADVANCED HEAT-SINK DESIGN. II. P. A. Libby. Polytech. Inst. Bklyn., Dept. Aero. Eng. & Appl. Mech., PIBAL Rep. 535 (USAF WADD TN 59-424, Pt. II), Jan., 1960. 52 pp. 39 refs. Analysis of the capability of a composite slab of beryllium oxide (BeO) and beryllium (Be) to absorb the heating associated with the re-entry of a high performance ballistic missile. The trajectory considered corresponds to a ballistic factor (W/C_DA) equal to 2,000 lbs. per sq. ft., a re-entry velocity of 20,000 ft. per sec., and a re-entry angle of 20°. The numerical results indicate that the maximum permissible heat transfer rates for the trajectory are obtained with a relatively thin slab of beryllium oxide. The addition of beryllium to this slab may be required for structural and thermal shock considerations but does not greatly improve the heat-sink capabilities. The permissible values of the heat transfer parameter are applied to a slender cone with a spherical cap of 0.25 ft. nose radius. It is shown that for laminar flow no heat transfer reduction is required on the cone, while for turbulent flow, a reduction to 1/2 is required.

EFFECT OF BUOYANCY FORCES ON MASS TRANSFER COOLING. R. Eichhorn. U. Minn. Inst. Tech. Dept. Mech. Eng. HTL TR 25 (AFOSR TN 60-64), Feb., 1960. 15 pp. Analysis considering the constant-property laminar boundary layer equations with free convection and mass transfer. It is shown that similar solutions are possible for blowing rate distributions varying as the distance from the leading edge raised to the power $(n - 1)/4$, where n is the exponent in a power law surface temperature distribution. Solutions to the equations in the form of skin friction and heat transfer parameters, and velocity and temperature profiles are presented for the constant wall temperature case for a fluid with $Pr = 0.73$. The cases considered range from strong suction to strong blowing. Mass transfer is shown to have a pronounced effect on the heat transfer but only a slight effect on the skin friction.

Boundary Layer

THE EFFECT ON PROFILE DRAG OF RANDOMLY DISTRIBUTED, LOW-DENSITY ROUGHNESS. W. S. Coleman. Blackburn Aircraft Rep., Jan., 1960. 28 pp. 17 refs. Analysis of the effect of random, or accidental, roughness on the behavior of the boundary layer in terms of the turbulent spots generated by the excrescences. Functions defining the probability distribution of lami-

nar and turbulent flow at any cross section of the boundary layer are obtained from (a) the kinematic properties of spots, and (b) the transition theory of Emmons. The two approaches are found to lead to substantially the same result. Finally, the influence of the roughness on wing profile drag is considered. It is shown that an appreciable increase of drag may be expected to develop when the mean spacing of the critical excrescences near the leading edge falls below about 0.5 of the chord.

LIFT GENERATION ON A CIRCULAR CYLINDER BY TANGENTIAL BLOWING FROM SURFACE SLOTS. V. E. Lockwood. US, NASA TN D-244, May, 1960. 38 pp. OTS, $1.00. Presentation of results of an investigation on the generation of lift on a circular cylinder which had a fineness ratio of 8 with an end-plate of 2.5 diam. The investigation was made to determine to what extent the lift and drag characteristics were influenced by slot number, slot combination, slot position, and blowing momentum coefficient. The results can be correlated with those of a jet-flap wing on the basis of equal drag.

TESTS OF AN AREA SUCTION FLAP ON AN NACA 64A010 AIRFOIL AT HIGH SUBSONIC SPEEDS. D. W. Smith and J. H. Walker. US, NASA TN D-310, May, 1960. 43 pp. OTS, $1.25. Study of the possibilities of preventing shock-induced separation on a wing with a plain flap through the use of area suction, and hence, of reducing the drag of the wing. The lift, drag, chordwise distribution of static pressure, and boundary-layer profile at 0.85c were measured for a two-dimensional wing. A reduction of the section drag coefficient for a constant section lift coefficient was obtained by application of suction over the area from 69 to 72.5% of the wing chord. The largest reduction was obtained for the model with less than 2° flap deflection at Mach numbers of 0.80 and 0.82 for lift coefficients above about 0.35. However, for the highest lift coefficients at the test Mach numbers of 0.80 and 0.82, nearly the same reduction was obtained with the flap deflected 6° without suction.

NUMERICAL SOLUTIONS OF SHOCK-INDUCED UNSTEADY BOUNDARY LAYERS. S. H. Lam. Princeton U. Dept. Aero. Eng. Rep. 480 (AFOSR TN 59-926), Aug., 1959. 37 pp. Extension of previous work to provide numerical solutions for the shear function $\phi(\alpha, \beta)$ and the Reynolds analogy coefficient Ra, using a digital computer. It is found that the iterative procedure suggested previously was successful in generating solutions of good accuracy for the shear function $\phi(\alpha, \beta)$. However, because of the lack of a suitable "momentum integral correction" procedure, the iteration for the enthalpy function $H(\alpha, \beta)$ was found to be unsatisfactory.

ON THE RESPONSE OF THE LAMINAR BOUNDARY LAYER TO SMALL FLUCTUATIONS OF THE FREE-STREAM VELOCITY. Nicholas Rott and M. L. Rosenzweig. J. Aerospace Sci., Oct., 1960, pp. 741-747, 787. 10 refs. Extension of the linearized tratment of small time-dependent disturbances in a laminar boundary layer, initiated by Lighthill. In particular, the high-frequency expansion is continued beyond the leading (Stokes) term. In addition, a practical method for obtaining the response of the laminar boundary layer to an impulsive change in velocity is presented. The methods are applied to the case in which the basic steady flow belongs to the Falkner and Skan family of similarity solutions.

LAMINAR SEPARATION IN SUPERSONIC FLOW WITH EMPHASIS ON THREE-DIMENSIONAL PERTURBATIONS AT REATTACHMENT. J. J. Ginoux. TCEA TN 3 (AFOSR TN 60-237), Feb., 1960. 42 pp. Investigation showing that regular and repeatable spanwise flow perturbations exist in the reattachment region of a laminar supersonic boundary layer on a two-dimensional backward-facing step model. It is found that the model span and leading-edge thickness, when below 0.1 mm., had no effect on the wavelength of the flow perturbations. On backward-facing steps, at a Mach number of 2.16, the ratio of wavelength of the flow perturabations to boundary-layer thickness was a function of the ratio of step height to boundary-layer thickness. Similar perturbations were found at the reattachment region of a laminar boundary layer on forward-facing steps, on compression corners, on rectangular cavities, and in the case of interaction between a shock wave and the bound ary layer. They were also detected in unseparated boundary layers.

Flow of Fluids

MATHEMATICS AND AERONAUTICS. Appendix - ACOUSTIC-THEORY APPROACH TO THE POTENTIAL OF A LINE SOURCE. M. J. Lighthill. (48th Wilbur Wright Memorial Lecture, London, May 19, 1960.) RAeS J., July, 1960, pp. 375-393; Discussion, pp. 393, 394. 52 refs. Review of the interaction of mathematics and aircraft development with particular emphasis on slender-body theory. The concept of big-scale flow and the calculation of wave drag are shown. The lift distribution in unseparated flow, considering steady-flow effects of incidence or longitudinal camber and unsteady pitching moments, both rigid and aeroelastic, are then considered. The accuracy of the slender-body theory is reviewed by theoretical and experimental means. Finally, the equation of lift for separated cross flows is given, and some problems requiring solution are discussed.

ON AN APPROXIMATE SOLUTION OF THE ENERGY EQUATION AND ITS APPLICATION TO THE McCLIMANS' DATA. E. E. Covert. MIT NSL TR 403, Nov., 1959. 27 pp. Presentation of an approximate solution to the energy equation for low-speed pipe flows using the Kirchhoff transformation. In relatively low-speed flows the viscous dissipation is very small compared to the conducted and convected energy. An approximate solution is found in terms of the variable which indicates that the usual parameters in forced convection can be generalized to allow for high rates of heat transfer

and variable fluid properties. The solution is used to correlate the heat transfer data from McClimans experiment on magnetohydrodynamic skin friction.

RESEARCH ON TRANSONIC AND SUPERSONIC FLOW OF A REAL FLUID AT ABRUPT INCREASES IN CROSS SECTION (WITH SPECIAL CONSIDERATION OF BASE DRAG PROBLEMS). H. H. Korst, W. L. Chow, and G. W. Zumwalt. U. Ill. Eng. Exp. Sta. MED ME Final TR 392-5 (AFOSR TR 60-74), Dec., 1959. 151 pp. 44 refs. Summarized presentation of a general theory for pressures and temperatures in separated transonic and supersonic flows, using a physical model composed of simplified flow components. The principle of interaction between dissipative and free-stream flow regions allows a distinction to be made between inviscid flow configurations and superimposed jet mixing regions. A great variety of problems in internal and external flow is analyzed theoretically, ranging from the classical base pressure problem to the performance of supersonic ejectors, and a detailed study of the jet-slipstream interaction problem in jet engine and rocket propulsion is made.

THE HYDRODYNAMIC STABILITY OF A THIN FILM OF LIQUID IN UNIFORM SHEARING MOTION. J. W. Miles. J. Fluid Mech., Aug., 1960, pp. 593-610. 15 refs. Presentation of solutions for large values of the Reynolds number R concerning the stability problem of a thin film of liquid having a linear mean-velocity profile and bounded by a fixed wall and free surface. The analysis is similar to that for plane Couette flow, but instability occurs for sufficiently large values of R in accordance with Heisenberg's criterion that neutral disturbances having finite wave number and phase velocities for $R = \infty$ are necessarily unstable as $R \rightarrow \infty$. It is found that a sufficient condition for stability is $W < 3$, where W is the Weber number based on the mean speed of the free surface and the depth of the film. The minimum critical Reynolds number, also based on free surface speed and film depth, is to be $R = 203$. Neutral stability curves are presented in an R vs. α (= wave number) plane with W as the family parameter. Brief consideration also is given to the time-rate-of-growth of unstable disturbances and to the lighter fluid that, in actual configuration, is responsible for the shear in the film.

AN INVESTIGATION OF INDUCED-PRESSURE PHENOMENA ON AXIALLY SYMMETRIC, FLOW-ALINED, CYLINDRICAL MODELS EQUIPPED WITH DIFFERENT NOSE SHAPES AT FREE-STREAM MACH NUMBERS FROM 15.6 TO 21 IN HELIUM. J. N. Mueller, W. H. Close, and Arthur Henderson, Jr. US, NASA TN D-373, May, 1960. 48 pp. 22 refs. OTS, $1.25. Presentation of induced-pressure data showing that the highest induced pressures occur on the bluntest (flat nose) configuration; as the nose shapes decreased in bluntness, the induced pressures also decreased. Beyond 20 model diameters from the nose-cylinder juncture, the induced pressures become essentially independent of the degree of nose bluntness. The induced pressures correlate on the basis of blast-wave-theory parameters; thus, the induced pressures are a function of nose drag but are essentially independent of nose shape beyond one model diameter downstream of the models' shoulders. Unmodified blast-wave theory is found to be inadequate for predicting induced pressures except in very limited regions. A modified form of blast-wave theory is shown to give good agreement with experimental results when experimentally determined viscous effects were incorporated. Comparison of experimental induced pressures and shock shapes obtained on 90° conical-tip configurations with characteristic-theory calculations for similar configurations shows good agreement.

FREE MOLECULE FLOW OVER NON-CONVEX BODIES. I. M. Cohen. Princeton U. Dept. Aero. Eng. Rep. 497 (AFOSR TN 60-190), Feb., 1960. 35 pp. 19 refs. (Also in ARS J., Aug., 1960, pp. 770-772.) Analysis to determine the velocity distribution function f and the heat transfer rate at any point on the surface of an arbitrary nonconvex body. A theory is developed in which the mass flux incident on the surface of the body is expressed as the solution of an integral equation. Then, the fundamental transport properties at the surface are given in terms of appropriate integrals over velocity space.

O SUSHCHESTVOVANII SLABOGO RESHENIIA PRIAMOI ZADACHI TEORII OBTEKANIIA PROFILIA ZVUKOVYM POTOKOM V PERVOM PRIBLIZHENII. F. I. Frankl'. AN SSSR Dokl., June 1, 1960, pp. 789-792. 13 refs. In Russian. Application of the hodograph method to solve the problem of flow about a smooth profile, analogously to that of transonic flow in Laval nozzles. The case considered is similar to the case of symmetrical flow about symmetrical profiles, and the problem is solved in the first approximation by linearizing the boundary conditions. The existence of a weak solution to the problem is shown.

HYPERSONIC FLOW OVER AXIALLY SYMMETRIC SPIKED BODIES. D. J. Maull. J. Fluid Mech., Aug., 1960, pp. 584-592. Investigation of flow over spiked bodies at a Mach number of 6.8. It is shown that while fitting a spike to the nose of a blunt body may reduce the drag coefficient, it may in some cases cause a rapid fluctuation of the flow pattern and thus produce an unsteady drag coefficient. The practical use of such a device must therefore be limited to bodies which do not exhibit these changes in flow pattern. The length of the spike will also be determined by structural considerations and the shorter the spike the more the nose shape must tend toward a hemisphere for steady flow.

SECOND-ORDER THEORY FOR UNSTEADY SUPERSONIC FLOW PAST SLENDER, POINTED BODIES OF REVOLUTION. J. D. Revell. J. Aerospace Sci., Oct., 1960, pp. 730-740. 14 refs. Analysis of the second-order effects of thickness

on the unsteady aerodynamic flows on a pointed body of revolution. The solution is obtained by approximating the nonlinear terms in the second-order potential equation by their first-order values and solving the resulting inhomogeneous partial differential equation, subject to more refined boundary conditions. The pressure equation is likewise refined and integrated to give the second-order corrections to lift and pitching moment coefficients. The analysis can be considered as an extension of the second-order, slender body theory of Lighthill to the case of unsteady flow. The results indicate appreciable reductions in unsteady lift and damping moment coefficients when applied to slender cones.

A STUDY OF THE ASYMMETRIC TRANSONIC FLOW PAST A SHARP LEADING EDGE. Appendix A - DESCRIPTION OF X-RAY DENSITOMETER EQUIPMENT, DENSITOMETER OPERATION, AND THE DENSITY DETERMINATION PROCESS. Appendix B - THEORETICAL CALCULATIONS. H. A. Stine, C. B. Wagoner, and A. L. Lugn, Jr. US, NASA TR R-66, 1960. 108 pp. 27 refs. Comparison of experimentally determined features of the flow field about the leading edge of a 12° wedge having the lower surface inclined at an angle of 13° to the air stream at nearly choked flow in the wind tunnel, with the calculated features corresponding to unbounded flow past the same body at a Mach number of exactly unity. From the flow surveys the following features are determined: the location of the stagnation point, the location of the sonic line, the size of the separation bubble on the upper surface, and the value of the Mach number at the bubble edge. The calculations yield a separation bubble on the upper surface which has a shape shown to be compatible with known theoretical conditions for viscous attachment to the upper surface of the body. Agreement between calculated and experimentally determined results is good in regions where the local Mach number was 2 or less. In regions of higher local Mach number the agreement was fair.

SHEAR AND HEAT FLOW FOR MAXWELLIAN MOLECULES. S. Ziering. Phys. Fluids, July-Aug., 1960, pp. 503-509. 15 refs. Evaluation of the half-range collision integrals for Maxwellian molecules for problems of shear and heat flow between parallel plates. The inverse fifth law of molecular interaction is regarded as a lower bound for neutral gases. The equations governing shear and heat flow, respectively, are completely discoupled in a linear treatment and can be easily extracted by superposition of the two separate solutions.

FLAT PLATE DRAG IN MAGNETOHYDRODYNAMIC FLOW. H. P. Greenspan. Phys. Fluids, July-Aug., 1960, pp. 581-587. 10 refs. Analysis considering sub-Alfvén magnetohydrodynamic flow past a flat plate, in which the vorticity generated within the fluid is propagated upstream by Alfvén waves and produces a forward disturbance which, in form, is very similar to the viscous wake. The structure and strength of the wake and precursor are examined and compared for large Reynolds numbers and finite conductivity. As the conductivity increases, a larger proportion of the total vorticity is propagated upstream so that the precursor becomes more pronounced and the wake weakens. Explicit formulas for the skin friction and drag coefficient are determined for arbitrary values of the conductivity, and the results clearly exhibit the effects of the interaction of fluid flow and magnetic field.

MAGNETOHYDRODYNAMIC SIMPLE WAVES. J. D. Cole and Y. M. Lynn. GALCIT Rep. (AFOSR TN 59-1302), Dec., 1959. 52 pp. Study of simple wave flows of an infinitely conducting perfect gas (polytropic) in the presence of an arbitrarily oriented magnetic field. From group theoretic considerations, the problem is reduced to the solution of a first-order differential equation which is integrated numerically. Properties of solutions and examples are discussed.

OSNOVNYE SOOTNOSHENIIA NA SIL'NOI STATSIONARNOI UDARNOI VOLNE, VYZYVAIUSHCHEI SKACHOK PROVODIMOSTI. Iu. L. Zhilin. Prikl. Mat. i Mekh., May-June, 1960, pp. 543-546. In Russian. Discussion of phenomena occurring during the motion of shock waves in media with infinite conductivity, of importance in astrophysical problems involving high Reynolds numbers. The importance, for high-speed aerodynamics, of the study of strong shock waves in media in which the conductivity ahead of the shock wave is absent and reaches high values behind it, due to the ionization process within the wave, is evaluated. The motion of a strong shock wave in a gas is studied for the case of given electromagnetic field ahead of the wave. It is assumed that ahead of the wave there are no currents due to the low conductivity, and the electric and magnetic fields can be chosen arbitrarily. In order to establish a relationship between the parameters of the gas and the field during the passage of such a wave, the equations of motion of the gas in the presence of an electromagnetic field are studied.

ANALYSIS OF STEADY-STATE SUPPORTED ONE-DIMENSIONAL DETONATIONS AND SHOCKS. W. W. Wood. Phys. Fluids, July-Aug., 1960, pp. 549-566. 19 refs. Analysis considering possible steady one-dimensional flows that can occur in a medium in which an arbitrary number of chemical reactions proceed behind an initiating shock, and investigation of the stability of solutions to the chemical rate equations. For detonations, it is shown that under suitable conditions on the rate functions, there are stable solutions resulting in an equilibrium final state for detonation velocities equal to or greater than the "equilibrium Chapman-Jouquet (C-J)" value corresponding to tangency of the Rayleigh line and the equilibrium Hugoniot. The final state of such a flow is a high-pressure intersection of the Rayleigh line and the equilibrium Hugoniot. The "normal frozen C-J condition," corresponding to attainment of chemical equilibrium at a point where the flow velocity is

sonic with respect to the "frozen" or high-frequency sound speed, is shown to result in an unstable solution.

CALCULATED EFFECTS OF BODY SHAPE ON THE BOW-SHOCK OVERPRESSURES IN THE FAR FIELD OF BODIES IN SUPERSONIC FLOW. D. L. Lansing. US, NASA TR R-76, 1960. 37 pp. 10 refs. Review of a theory developed by Whitham for the supersonic flow about bodies in uniform flight in a homogeneous medium, and reduction of an integral which expresses the effect of body shape upon the flow parameters in the far field to a form which may be readily evaluated for arbitrary body shape. This expression is then used to investigate the effect of nose angle, fineness ratio, and location of maximum body cross section upon the far-field pressure jump across the bow shock of slender bodies. Curves are presented showing the variation of the shock strength with each of these parameters. It is found that, for a wide variety of shapes having equal fineness ratios, the integral has nearly a constant value. Hence, to a first order, the pressure jump in the far field is independent of the shape and depends only upon the fineness ratio.

STARKE KUGELSYMMETRISCHE VERDICHTUNGSSTÖSSE UNTER BERÜCKSICHTIGUNG VON DISSOZIATIONS- UND IONISATIONSVORGÄNGEN. Ingolf Teipel. ZFW, July, 1960, pp. 187-202. 17 refs. In German. Calculation of a converging spherical shock wave considering the effects of dissociation and ionization. Behind the shock front, the flow is assumed to be quasi-steady, an assumption which gives the exact solution at high pressures for ideal gases of constant specific heats. Hydrogen is used as the working medium. It is shown that the gas is nearly completely dissociated before the ionization begins. The equations become very simple when the gas behind the shock front has been ionized.

PISTON THEORY APPLIED TO STRONG SHOCKS AND UNSTEADY FLOW. J. L. Raymond. J. Fluid Mech., Aug., 1960, pp. 509-513. Extension of piston theory to flows with strong shocks by the removal of the restriction of isentropic flows. Sample calculations for a thin biconvex airfoil are carried out in which the local flow is assumed to be isentropic and nonisentropic. Comparison of the result is made with that of the shock expansion theory of Cole, Gazley, and Williams.

INFLUENCE OF PRESSURE HISTORY ON MOMENTUM TRANSFER IN RAREFIED GAS FLOWS. F. C. Hurlbut. Phys. Fluids, July-Aug., 1960, pp. 541-544. Investigation of the coefficient of tangential momentum transfer σ between the boundary and a flow of rarefied gas, using the rotating cylinder technique. Systematic perturbation of the pressure history of the active surfaces is made and correlated with observed variations of σ. A high-pressure history is found to result in a lowering of σ with time from values in the range 0.9 to 1.0 to values approaching 0.6. A low-pressure history is found to result in constant values of σ in the range 0.9 to 1.0. The observations were of the same character for all gases.

ON THE PREDICTION OF MIXED SUBSONIC/SUPERSONIC PRESSURE DISTRIBUTIONS. C. S. Sinnott. J. Aerospace Sci., Oct., 1960, pp. 767-778. 16 refs. Analysis of high-speed wind tunnel results to derive a semiempirical scheme for the prediction of transonic pressure distributions. The supersonic and subsonic parts of the flow are treated separately, and then linked by an empirical shock pressure rise relation. The significance of the empirical results is considered in relation to the physical mechanism of transonic flows. It is also shown that theoretical solutions can be improved by introducing the empirical shock relation.

A NUMERICAL APPROACH TO THE QUESTION OF STABILITY OF SUPERSONIC ENCLOSURES IN AN OTHERWISE SUBSONIC FLOW FIELD. Wolfgang Werner. Munich Tech. Hochsch. Math. Inst. TN 12 (EOARDC TN 60-256), Dec. 7, 1959. 35 pp. Results of a numerical investigation covering the stability of transonic flow past a profile. An "exceptional" solution is calculated, describing a steady, continuous transonic flow. This solution is used as initial data for a time dependent numerical calculation. Results seem to indicate the existence of stable transonic flows with shocks.

TURBULENCE THEORY AND FUNCTIONAL INTEGRATION. I, II. Gerald Rosen. Phys. Fluids, July-Aug., 1960, pp. 519-528. 18 refs. Presentation of an integral representation of the general solution of the Hopf Φ equation. Integral representations for the spatial correlation functions are derived from the characteristic functional Φ. These exact results are applied to Navier-Stokes fluid turbulence. Proofs are given which show that the integral representations for the Navier-Stokes spatial correlation functions satisfy the reality conditions, the continuity conditions, and the Navier-Stokes condition. With the aid of the integral representations for the correlation functions, an analysis of the decay of homogeneous turbulence is developed.

Internal Flow

PROPAGATION OF WAVES OF FINITE AMPLITUDE ALONG A DUCT OF NON-UNIFORM CROSS-SECTION. Jan Rościszewski. J. Fluid Mech., Aug., 1960, pp. 625-633. Analysis concerning wave propagation along a duct of initially constant and then slowly varying cross section. The equations of motion are linearized in the deviations from the simple wave solution. The solution for the propagation of a centered simple rarefaction wave is obtained in closed form and compared with the results of step-by-step calculations. The results are also found to be good when the area change is not small. Some remarks on boundary-layer influence are included.

PRESSURE MEASUREMENTS ON THREE OPEN NOSE AIR INTAKES AT TRANSONIC AND SUPER-

SONIC SPEEDS, WITH AN ANALYSIS OF THEIR DRAG CHARACTERISTICS. Appendix I - A COMPARISON OF DIFFUSER PRESSURE RECOVERY WEIGHTED ON A MASS FLOW AND ON AN AREA BASIS. Appendix II - ANALYSIS OF THE NOSE SHOCK WAVE SHAPE AND THE DETERMINATION OF WAVE DRAG. J. C. Gibbings. Gt. Brit., RAE Rep. Aero. 2637, Mar., 1960. 97 pp. 24 refs. Description of tests on three air intakes at zero incidence over a Mach number of 0.80 to 1.82. External pressure distributions, diffuser pressure recoveries, and drags are obtained for a range of mass flow ratios. At supersonic speeds, measurement of the nose shock wave shape made possible the division of the external drag into wave and separation drags. Comparisons with theoretical values are made for the pressure distributions, pressure recovery, nose shock wave shape, wave drag, and external drag.

EFFECT OF TRANSVERSE ACOUSTIC OSCILLATIONS ON THE VAPORIZATION OF A LIQUID-FUEL DROPLET. P. R. Wieber and W. R. Mickelsen. US, NASA TN D-287, May, 1960. 25 pp. 18 refs. OTS, $0.75. Development of three differential equations to express the drop acceleration in the axial and transverse directions and the rate of change in radius of the drop with time, defined as the vaporization rate. The equations were solved on an analog computer for a range of gas conditions; histories of the drop velocities, displacements, radius, and rate of change of radius with time were obtained. Results show that in an acoustic field a drop acquires an oscillating transverse velocity and a fluctuating vaporization rate. The time required to vaporize 97% of the drop mass was reduced as acoustic-field frequency and amplitude were increased. The increase in vaporization rate was suggested as a possible cause of the increased combustion efficiency noted under unstable combustion conditions for an initially inefficient combustor.

Performance

SOME REQUIREMENTS FOR THE EFFICIENT ATTAINMENT OF RANGE BY AIRBORNE VEHICLES. M. Arens. ARS J., Aug., 1960, pp. 730-734. Evaluation of the efficiency of attaining range using either a level cruise or ballistic trajectory by means of a suitable range factor for both trajectories. Use of this factor also allows comparison between aircraft using power plants of different specific weight and fuel consumption. The ballistic trajectory is examined, and the region in which it is inherently superior to a level cruise trajectory is described as a function of cruising L/D and range. The optimum speeds for cruising flight are determined.

Stability & Control

THE LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF A SWEPTBACK WING-BODY COMBINATION WITH AND WITHOUT END PLATES AT MACH NUMBERS FROM 0.40 TO 0.93. W. P. Henderson. US, NASA TN D-389, May, 1960. 22 pp. 14 refs. OTS, $0.75. Investigation indicating that the addition of the end plates to either the wing with drooped chord-extensions or to the wing without drooped chord-extensions slightly increased the lift in the low angle of attack range but slightly decreased the lift at moderate and high angles of attack. The addition of the end plates to the wing without the chord-extensions caused a small increase in the maximum lift-drag ratio at Mach numbers below 0.65 and a slight decrease at the higher Mach numbers; however, for the addition of the end plates to the wing with the chord-extensions, the maximum lift-drag ratio was slightly decreased below a Mach number of 0.88, while a slight increase occurred for the higher Mach numbers. The addition of the end plates to the wings with and without the chord-extensions caused the longitudinal stability to increase considerably for all Mach numbers; only a slight reduction in the aerodynamic-center variation with Mach number was observed.

DYNAMIC LONGITUDINAL STABILITY AND RESPONSE CHARACTERISTICS OF JET-FLAP AIRCRAFT. A. S. Taylor. Gt. Brit., RAE TN Aero. 2670, Feb., 1960. 71 pp. 11 refs. Extension of the generalized stability and control investigation, based on Spence's two-dimensional data, by a study of dynamic stability and of comparative response characteristics for step-inputs of tail and jet controls. From numerical examples it is concluded that in the basic design (high lift) condition, the quasi-steady maneuverability criterion is not a valid basis for comparison of control effectiveness, because a divergent phugoid of relatively short period, coupled with a rapid oscillation of relatively long period, prevents the establishment of a quasi-steady condition. Because the initial response is much slower for tail control than for jet controls, it appears that jet deflection control may be more effective than tail control for this case. The maneuverability criterion is shown to remain substantially valid for the cruising condition, however, and the superiority of tail control over jet controls in this case is confirmed.

INERTIA CROSS-COUPLING EFFECTS DURING ROLLING OF A DELTA AIRCRAFT (BOULTON-PAUL IIIA). J. E. Nethaway and J. Clark. Gt. Brit., RAE TN Aero. 2674, Feb., 1960. 31 pp. Flight investigation of the effects of various parameters such as rate of roll, roll direction, and control movement. An approximate theory is used to check its usefulness as a guide to the trend of results, and a typical roll record is compared with the time history record calculated by an analog computer. During the tests, it was apparent that the pilot had no direct appreciation of the increase in incidence or sideslip, until the aircraft started to buffet during the roll.

Wings & Airfoils

THE DRAG AND STABILITY OF A CIRCULAR WEDGE AIRFOIL IN SUPERSONIC FLIGHT. M. J. Piddington and Ch. H. Murphy. US, BRL Memo. Rep. 1245, Jan., 1960. 21 pp. Presentation of test results for airfoil models in a ballistic range. Re-

sults show that at Mach numbers in excess of 1.8, triangular cross section ring airfoils with centrally located centers of gravity are quite stable. This stability deteriorates rapidly for lower Mach numbers. The linearized theory provides a good estimate of form drag, and the static moment coefficient is well approximated by a linear function of thickness ratio.

EXPERIMENTAL LIFT AND DRAG OF A SERIES OF GLIDE CONFIGURATIONS AT MACH NUMBERS 12.4 AND 17.5. R. E. Geiger. IAS Natl. Summer Meeting, Los Angeles, June 28-July 1, 1960, Paper 60-92. Members, $0.50; nonmembers, $1.00. 34 pp. Investigation of a series of semi-ballistic type bodies consisting of three half sphere-cones of 0.3 bluntness ratio with half cone angles of 8.6°, 13°, and 18°. In addition, a representative winged glide configuration consisting of a sharp edged, 60° swept delta wing with cone-segment "body" was tested with and without the "body" at a Mach number of 12.4. The angle of attack range for the half sphere-cone tests was ±65°; for the delta wing it was ±20°. The technique for force coefficient determination consists of analyzing high-speed motion pictures of the motion of very light balsa and Isofoam plastic models which are literally free-flown for several milliseconds in the shock tunnel test section. In general, the drag of the half sphere-cones is reasonably well predicted by simple Newtonian theory. Newtonian lift predictions, however, are not good in the low and medium angle of attack range, being especially poor for the positive angle of attack.

AN INTRODUCTION TO THE FLOW ABOUT PLANE SWEPT-BACK WINGS AT TRANSONIC SPEEDS. E. W. E. Rogers and I. M. Hall. RAeS J., Aug., 1960, pp. 449-464. Study of the manner in which the flow develops about wings with leading edges swept at about 50° as the stream Mach number rises from a subsonic to a supersonic value. The shock pattern which occurs is shown to be of a complex nature. Three aspects of the wing flow are discussed in more detail, including the flow near zero lift and at moderate and high lift. The possible conditions for shock-induced separation of the surface boundary layer, and the effect of the changing flow pattern on the overall wing lift, drag, and pitching moment are commented upon.

SOME MEASUREMENTS IN THE VORTEX FLOW GENERATED BY A SHARP LEADING EDGE HAVING 65 DEGREES SWEEP. N. C. Lambourne and D. W. Bryer. Gt. Brit., ARC CP 477, 1960. 12 pp. BIS, New York, $0.36. Investigation of the vortex flow which arises when separation occurs at a highly swept leading edge. Measurements are made in the flow over flat plates at 15° incidence each having a sharp leading edge. The pressure and velocity distributions, both along the axis of the vortex and for one cross section of the flow, are presented together with a preliminary discussion of their significance.

EFFECT OF STREAMLINE CONTOURING IN THE WING-FUSELAGE JUNCTURE IN COMBINATION WITH THE SUPERSONIC AREA RULE ON A SWEPTBACK-WING - FUSELAGE CONFIGURATION OF HIGH FINENESS RATIO. Ch. D. Trescot, Jr. US, NASA TN D-387, May, 1960. 19 pp. OTS, $0.50. Comparison of two methods for reducing the pressure drag of a high-fineness-ratio wing-body combination at a Mach number of 1.3. One configuration was axisymmetrically indented according to the principles of the supersonic area rule, and the other configuration employed the streamline concept of shaping the wing-fuselage juncture with the same longitudinal area development as that of the supersonic-area-rule configuration. The results of the investigation indicate that, for a relatively slender configuration, the streamline concept of shaping the fuselage does not offer pressure-drag reduction greater than that obtainable with the supersonic-area-rule concept.

CONTRIBUTION EXPERIMENTALE AU CALCUL DE CONFIGURATIONS DU TYPE CANARD. E. Erlich. La Recherche Aéronautique, Mar.-Apr., 1960, pp. 15-21. In French. Presentation and evaluation of experimental results obtained on several forward-wing - rear-wing configurations, located in the plane of symmetry of a cylindrical ogival fuselage, to verify a theory developed recently by Baranoff. It is shown that the theoretical method, extended to the supersonic range through a simple empirical approach, can be applied to the calculation of the interaction in lift between the forward and the rear wing. The position of the point of application of this interaction force is determined from the slender-body theory. Experimental results confirm the calculated pitching moment to a good approximation. The method is of particular interest when used to estimate the change in the already experimentally known properties of a wing-body configuration due to the forward wing.

SUPERSONIC FLIGHT MEASUREMENTS OF NORMAL FORCE AND CENTRE OF PRESSURE POSITION FOR A RELATED SERIES OF WINGED BODIES. J. A. B. Cartmel. Australia, WRE TN SAD 45, Aug., 1959. 32 pp. Presentation of free flight results in which normal force translation derivatives and centers of pressure were investigated for a related series of low-aspect-ratio, rectangular wings fitted to a cone-cylinder body. The results are shown for seven planforms for supersonic speeds below a Mach number of 1.7.

AEROELASTICITY

SUPERSONIC FLUTTER ANALYSES INCLUDING AERODYNAMIC HEATING EFFECTS. Appendix I - ANALYSIS TO GIVE REQUIRED SKIN THICKNESS NECESSARY TO PREVENT FAILURE AT ROOT. Appendix II - ELECTRICAL ANALOGIES FOR SECOND ORDER PISTON THEORY AERODYNAMICS. Appendix III - BURROUGHS 205 PROGRAM FOR THE THERMAL EQUATION. Appendix IV - SUMMARY OF THE THERMAL PARAMETERS FOR THE BASIC WING. R. L. Harder, K. Lock, D. G. McCann, C. H. Wilts, and

W. W. Royce. USAF WADC TR 59-559, Feb., 1960. 260 pp. Study of a straight wing with an aspect ratio of 2, a taper ratio of 0.5, and a 4% thickness, maneuvering in a Mach number range from one to five. The study has led to the development of a number of analog and digital methods of computation for various required analyses including aerodynamic heating, transient wing temperature calculations, inplane thermal stress calculations, effects of moduli changes and thermal stresses on structural properties of the wing in lateral bending, and supersonic flutter analysis using second-order piston theory. Flutter results are given for several specific maneuvers and show that neglecting the effects of heating in the calculation may lead to unconservative results.

EFFECTS OF TRANSIENT HEATING ON THE VIBRATION FREQUENCIES OF A PROTOTYPE OF THE X-15 WING. R. R. McWithey and L. F. Vosteen. US, NASA TN D-362, May, 1960. 21 pp. OTS, $0.75. Investigation of the effects of aerodynamic heating on the effective stiffness of a section of the X-15 wing. The aerodynamic heating rate distribution along the chord was obtained by means of radiant heaters positioned around the wing section which gave essentially identical heat inputs to the upper and lower surfaces. Changes in frequency of each of five natural modes of vibration of the wing section were determined to indicate changes in stiffness. The results show that the largest change in frequency, a decrease of 5%, occurred in the first torsion mode. The change in effective stiffness was calculated for the first torsion mode by using the experimental temperature distribution and was found to be in fair agreement with the measured value.

AIRPLANES

Air Conditioning, Pressurization

COOLING METHODS AND EQUIPMENT FOR SUPERSONIC AIRCRAFT. G. R. Werth, H. K. McCluer, and B. T. Fitchett. USAF WADC TR 57-619 [AD 151141], Feb., 1960. 166 refs. Study of methods for cooling the aircraft cabin and equipment including (1) air cycle, vapor cycle, and absorption cycle refrigeration; (2) rejection of heat to expendable coolants; and (3) relatively unexplored methods such as vortex tubes, thermoelectric cooling, and endothermic reactions. Some 28 cooling systems were conceived and analyzed, and the six most promising were evaluated to determine the drag horsepower attributable to each. Storage cooling systems using fuel and water as heat sinks were found to be the most promising. Vortex tubes and thermoelectric cooling are limited to the dissipation of small localized heat loads where their unique characteristics allow successful competition with more orthodox cooling methods. Endothermic reactions appear to have no value in cooling supersonic aircraft.

INSTRUMENTS

Flight Instruments

SEVERAL METHODS FOR AERODYNAMIC REDUCTION OF STATIC-PRESSURE SENSING ERRORS FOR AIRCRAFT AT SUBSONIC, NEARSONIC, AND LOW SUPERSONIC SPEEDS. V. S. Ritchie. US, NASA TR R-18, 1959. 23 pp. 25 refs. GPO, $0.40. Investigation for the verification of methods to reduce errors due to sensor position, bow-wave passage, and angle of attack. The results indicate that aerodynamic devices of simple design may be employed to reduce errors in sensing static pressures to less than 0.5% at Mach numbers from about 0.40 to 1.15.

MATERIALS

High Temperature

L'UTILISATION DU TEFLON COMME MATERIAU D'ABLATION. J. Cornillon. Docaéro, May, 1960, pp. 33-38. 15 refs. In French. Discussion of the use of Teflon as an ablation material, covering the advantages of ablation cooling; the chemistry of the composition of Teflon and formulas giving the speed of decomposition and the heat of depolymerization; application to the thermal protection of missiles; mechanism of the cooling effect; effect of the exponential character of the speed of decomposition of Teflon as function of the temperature; mass transfer; and the effect of gas injection in the boundary layer. The method of analysis is shown to be applicable to other materials when their decomposition characteristics are known.

Metals & Alloys

GENERAL RESEARCH IN FLIGHT SCIENCES - MECHANICS OF DEFORMABLE BODIES. XIII - THE EFFECT OF RESIDUAL STRESSES ON THE CRITICAL CRACK LENGTH PREDICTED BY THE GRIFFITH THEORY. W. E. Jahsman and F. A. Field. Lockheed Aircraft Missiles & Space Div., vol. II, TR LMSD-288139, Jan., 1960. 22 pp. Extension of the Griffith theory for unstable crack length to take into account the effect of residual (self-equilibrating) stresses. An expression relating the uniform stress, physical properties of the material, critical crack length, and the equilibrating strain energy is derived for a general residual stress distribution. This expression is used to develop a criterion for spontaneous cracking due to residual stresses alone. An example for a parabolic residual stress distribution in a beryllium plate is carried out.

MECHANICS

DYNAMICS OF FUEL IN TANKS. J. W. Addington. Coll. of Aeronautics, Cranfield, Note No. 99, Jan., 1960. 27 pp. Investigation of the validity of available theory for determining the natural frequency of the fundamental fuel sloshing mode in a rectangular tank. The results are found to agree within 5% over the whole range, and were quite accurate in the extreme "shallow and deep water" regions. A qualitative investigation into baffle types and positioning indicates that baffles should be positioned in a region of highest velocity such that the surface waves are trapped and the energy dissipated at the shallowest depth possible.

This suggests that for a tank with varying liquid depth, a multi-perforated baffle should be employed, having a total orifice area of one quarter the baffle area.

MISSILE, ROCKET, & SPACE TECHNOLOGY

SIMULATION OF FUEL SLOSHING CHARACTERISTICS IN MISSILE TANKS BY USE OF SMALL MODELS. H. N. Abramson and G. E. Ransleben, Jr. ARS J., July, 1960, pp. 603-612. 12 refs. Army-sponsored application of similitude theory to the problem of fuel sloshing in accelerated tanks to establish criteria for the design of model experiments. It is found that dynamic modeling is possible even if liquid viscosity is considered, and the ranges of significant parameters and the selection of model liquids are discussed. The results of experiments made with small models are compared with those obtained with full-scale tanks, for two different types of damping devices.

PARAMETRIC WEIGHT STUDY OF A MANNED SPACE ENTRY VEHICLE. O. A. Kelley. Aerospace Engrg., Oct., 1960, pp. 40-49, 77. Study showing a weight comparison or trend data between different vehicles and heat-protection schemes. Both lifting and ballistic-type entry vehicles are investigated for satellite and circumlunar missions. The structural cooling methods studied are radiation, ablation, and a combination radiation plus ablation. The results indicate that the weight of minimum-sized three-man vehicles increases with increasing L/D throughout the range studied and for all missiles and types of structural cooling studied.

THE DEPENDENCY OF PENETRATION ON THE MOMENTUM PER UNIT AREA OF THE IMPACTING PROJECTILE AND THE RESISTANCE OF MATERIALS TO PENETRATION. R. D. Collins, Jr., and W. H Kinard. US, NASA TN D-238, May, 1960. 41 pp. OTS, $1.25. Investigation indicating that the penetration of projectiles into quasi-infinite targets can be correlated as a function of the maximum momentum per unit area possessed by the projectiles. The penetration of projectiles into aluminum, copper, and steel targets was found to be a linear function while the penetration into lead targets was a nonlinear function of the momentum per unit area of the impacting projectiles. Penetration varied inversely as the projectile density and the elastic modulus of the target material for a given projectile momentum per unit area. Crater volumes were found to be a linear function of the kinetic energy of the projectile, the greater volumes being obtained in the target materials which had the lowest yield strength and the lowest speed of sound.

BASE FLOW CHARACTERISTICS OF MISSILES WITH CLUSTER-ROCKET EXHAUSTS. B. H. Goethert. IAS Natl. Summer Meeting, Los Angeles, June 28-July 1, 1960, Paper 60-89. Members, $0.50; nonmembers, $1.00. 49 pp. Theoretical and experimental investigation of flow patterns associated with cluster-nozzle exhausts. The characteristic altitudes for the change of the base flow pattern, particularly the critical altitudes for flow reversal from atmospheric air flowing into the base to backflow of heat exhaust gases toward the base, are determined. Significant flow parameters, such as base pressure, heat flux, and base thrust increments, are calculated and presented in graphs. The effect of shrouds around nozzle clusters is investigated with respect to base thrust increment and base heating.

GENERAL RESEARCH IN FLIGHT SCIENCES - MECHANICS OF DEFORMABLE BODIES. IX - SHOCK RESPONSE OF A NONLINEAR MISSILE SUSPENSION SYSTEM. E. Y. W. Tsui and P. Stern. Lockheed Aircraft Missiles & Space Div., vol. II, TR LMSD-288139, Jan., 1960. 43 pp. 10 refs. Presentation of solutions for the dynamic response of a missile package with linear and nonlinear isolators subjected to shock inputs. Analytical and analog methods are introduced to solve the differential equations of motion, with effects of damping considered in these methods. An analysis of the relative maximum response of a system to edgewise rotational drops is developed from a parametric study for the dynamic behavior as a function of the location of isolators. Results are plotted in dimensionless form, using responses obtained by the energy method as a reference. Finally, the effects of spring nonlinearity, damping, and the location of isolators on the design of suspension systems are discussed.

EQUATIONS OF MOTION OF A ROCKET-POWERED AIRCRAFT. Angelo Miele. Boeing Sci. Res. Lab. FSL Rep. 20, D1-82-0038, Jan., 1960. 24 pp. Derivation of equations governing the translational-rotational motion of a rocket-powered vehicle with respect to the fixed stars, then simplified by means of some engineering approximations. It is shown that, for a given flight and operating condition of the propulsion mechanism, the total thermoaerodynamic force is uniquely defined. However, its decomposition into thrust and aerodynamic force is arbitrary. An infinite number of definitions can be imagined for the thrust; for each of these there is a corresponding definition for the aerodynamic force. Finally, approximate equations are presented for studying the motion of the vehicle with respect to the earth.

Ballistics, Re-Entry

ON THE NUMERICAL COMPUTATION OF FREE TRAJECTORIES OF A LUNAR SPACE VEHICLE. J. M. J. Kooy and J. Berghuis. (10th Internatl. Astron. Congr., London, Aug. 31-Sept. 5, 1959.) Astronautica Acta, Fasc. 2-3, 1960, pp. 115-143. Analysis of trajectories for moon rockets beginning with the determination of the initial conditions of solar and lunar motion with respect to the geocentric, nonrotating reference system. A three-dimensional orbit is calculated, in which the vehicle approaches the moon to within about 11,000 km. in a position to observe the hidden lunar hemisphere, completes the loop, and returns again to

the vicinity of the earth. In this example, the launching site was chosen on the equator, and during the last stage of flight, a ballistic speed, just sufficient to bring the vehicle within lunar distance, was applied. In another analysis, the launching site was chosen along a Northern latitude (Cape Canaveral), and a hyperbolic speed was applied in the last burnout point. The effects of the application of a retro-rocket in the vicinity of the moon are also explored. In addition, the possibility of launching a moon satellite is also examined, and a corresponding orbit is computed. It appears that the Kepler motion of such a moon satellite (with respect to a selenocentric system of reference, and not rotating with respect to the celestial sky) is strongly influenced by the combined terrestrial and solar disturbances.

TRANSFER BETWEEN NON-COPLANAR ELLIPTICAL ORBITS. R. S. Long. Astronautica Acta, Fasc. 2-3, 1960, pp. 167-178. Analysis considering the problem of two-impulse transfer of a rocket with minimum expenditure of propellant between non-coplanar elliptical orbits. On the assumption that the eccentricities of the given orbits are small, a solution is obtained to the first order. A method is also indicated for obtaining a first-order solution when the angle between the planes of the given orbits is small and the eccentricities are fixed.

CONTINUOUSLY POWERED TERMINAL MANEUVER FOR SATELLITE RENDEZVOUS. N. E. Sears, Jr., and P. G. Felleman. (ARS Controllable Satellite Conf., Cambridge, Apr. 30-May 1, 1959.) ARS J., Aug., 1960, pp. 734-739. Presentation of a concept which uses a continuously powered maneuver to accomplish the terminal phase of a satellite rendezvous operation. The characteristics of several sample maneuvers are presented, including the transfer time, acceleration levels, characteristic velocity, and thrust direction. These maneuvers include a non-coplanar transfer between elliptic orbits, as well as the simpler case of coplanar maneuvers and circular orbits. The advantages of using continuously powered maneuvers are discussed along with parametric effects of the system constants on the characteristics of the maneuver.

THREE-DIMENSIONAL DRAG PERTURBATION TECHNIQUE. R. M. L. Baker, Jr. ARS J., Aug., 1960, pp. 748-753. 17 refs. USAF-supported extension of the astronomical special perturbation technique to three dimensions for the entry of space vehicles. Perturbations resulting from the asphericity of the earth and the rotation of earth's atmosphere are explicitly included, and the effects of ablation, cross winds, and lift are considered. Use of the variation-of-parameters perturbation technique allows a more efficient and accurate computation of a large class of entry orbits.

SATELLITE RE-ENTRY WITH LIGHTLY LOADED LIFTING VEHICLES. Appendix - VALIDITY OF THE SIMPLIFIED LIFT EQUATION IN THE PULL-OUT ANALYSIS. J. A. F. Hill. MIT NSL TR 429, Dec., 1959. 68 pp. 15 refs. USAF-supported analysis considering the use of lightweight lifting surfaces for the re-entry of earth satellites into the atmosphere. The general equations of motion of a vehicle in the earth's atmosphere are written using a parameter which combines the atmospheric density with the vehicle's wing loading. Approximate analytical solutions of these equations are then found for three special cases - pull-out from a given entry angle to horizontal flight, horizontal flight, and equilibrium glide. Peak heating and deceleration, for which expressions are obtained, occur in the pull-out. For a vehicle whose drag polar is known, it is possible to determine at what lift coefficient the pull-out should be flown to minimize the heating. Finally, a rough estimate is made of the size of lifting surface required for the re-entry of a 1,400 lb. satellite with a peak temperature limitation of 1,800°F. This turns out to be equal to the area which is required to limit the sea-level landing speed equal to 20 knots.

DYNAMICS AND THERMODYNAMICS OF RE-ENTRY. W. H. T. Loh. (4th Ballistic Missiles & Space Tech. Symposium, Los Angeles, Aug. 26, 1959.) J. Aerospace Sci., Oct., 1960, pp. 748-762. 15 refs. Summarized presentation of the approximate analytical solutions on velocity, altitude, range, deceleration, maximum deceleration, time rate and maximum time rate of average and local stagnation region heat transferred into a vehicle, total heat transferred into a vehicle, and time of flight for boost glide or orbital re-entry into planetary atmosphere for various kinds of re-entry trajectories. These trajectories include: (1) great circle flight at small angles of inclination, (2) great circle flight at large angles of inclination, (3) minor circle flight at small angles of inclination, (4) minor circle flight at large angles of inclination, (5) constant equilibrium temperature flight, (6) constant deceleration flight, (7) constant aerodynamic load factor flight, (8) constant rate of descent flight, (9) constant angle of inclination flight, and (10) constant rate of heat input flight.

LONGITUDINAL RANGE CONTROL DURING THE ATMOSPHERIC PHASE OF A MANNED SATELLITE REENTRY. Arthur Assadourian and D. C. Cheatham. US, NASA TN D-253, May, 1960. 46 pp. OTS, $1.25. Analysis showing the feasibility of guiding a manned satellite to some preselected destination by making use of the pilot to control the trajectory. A fixed cockpit coupled with an analog computer simulated a high-drag variable-lift class of re-entry vehicle. Two control methods were investigated, one making use of typical ground-controlled approach procedures and the other making use of onboard navigational aids. Terminal range of errors of the order of $\pm$ 20 miles were possible for a wide range of conditions.

ANALYSIS OF LOW-ACCELERATION LIFTING ENTRY FROM ESCAPE SPEED. F. C. Grant. US, NASA TN D-249, June, 1960. 21 pp. OTS,

$0.75. Extension of an earlier analysis of lifting satellite entry for circular orbit velocities to the case of parabolic orbit velocities. Simple formulas are derived which yield approximations to the minimum loadings for steep entries. The general advantage of operation on the high drag side of maximum lift-drag ratio is demonstrated analytically. The optimum character of modulation from maximum lift coefficient is shown. A principal parameter is shown to be the ratio of maximum lift coefficient to minimum drag coefficient. The analytical results are compared with those of detailed numerical integrations for an entry vehicle with a simplified but realistic lift polar.

Guidance, Control, Stability

DESIGN AND EVALUATION OF A RE-ENTRY GUIDANCE SYSTEM. H. Reismann and J. S. Pistiner. Astronautica Acta, Fasc. 2-3, 1960, pp. 79-114. 17 refs. Analysis of a fully automatic re-entry guidance system which will permit safe recovery of the vehicle within 0.02 nautical miles of a preselected point on the earth's surface for initial re-entry conditions achievable with existing equipment. The fully automatic system may be adapted to one in which the pilot becomes an integral part of the loop. The generality and overall flexibility of the proposed guidance scheme makes it applicable to a variety of controllable re-entry configurations.

SOME PROBLEMS OF POLAR MISSILE CONTROL. D. Best. RAeS J., Aug., 1960, pp. 482-488. Study of a polar-controlled missile in which maneuvers are carried out by rotations about roll and pitch axes. To represent the three-dimensional relationships, two graphical methods of projection are used: space and angular projection. Three types of roll control methods are compared, and the effects of roll errors on accurate interceptions are noted. The problem of a stabilized homing head which maintains the target seeker accurately along the line of sight independent of missile motion is considered. If this isolation is not perfect, couplings may arise which greatly affect performance. Such a roll coupling, called collimation error, is introduced by errors in alignment between the stabilizing gyro and the target tracking head. In addition, the effect of aberration, caused by the angular motion of the missile body from which spurious target movements appear, is taken into account. Finally, the use of simulators to assess these types of problems is discussed.

Spacecraft

A METHOD FOR PREDICTING THE LIFETIME OF A NEAR SATELLITE. R. E. Good. MIT NSL TR 418 (AFCRC TN 60-287), Jan., 1960. 57 pp. 21 refs. Study of the behavior of satellite orbits under the perturbing effect of atmospheric drag in order to determine the lifetime of a satellite. By dividing the satellite lifetime into three phases - circularization, spiral decay, and terminal - approximate methods can be developed to estimate the satellite lifetime in each phase. The method developed is based on the law of conservation of energy. It considers a differential loss in energy per revolution through the drag; and then by integrating for N number of revolutions, the total change in the ellipse shape is determined per revolution. The lifetime is then the sum of the revolutions in each phase.

PHYSICS

Geophysics

ISSLEDOVANIIA KOSMICHESKIKH LUCHEI I ZEMNOGO KORPUSKULIARNOGO IZLUCHENIIA PRI POLETAKH RAKET I SPUTNIKOV. S. N. Vernov and A. E. Chudakov. Uspekhi Fiz. Nauk, Apr., 1960, pp. 585-619. 17 refs. In Russian. Survey of data obtained from Soviet cosmic rockets and satellites on the cosmic rays and terrestrial corpuscular radiation. The apparatus is described and the results of measurements are presented for the outer region of terrestrial corpuscular radiation, covering its location in relation to the earth; the inner region of the high-intensity zone and its location in relation to the earth, the nature and energy of particles in this zone, as well as stability of the intensity; and radiation outside of the terrestrial magnetic field. An analysis of the obtained data and possible hypotheses on the source of terrestrial corpuscular radiation are also included.

POWER PLANTS

Jet & Turbine

AN ANALYSIS OF THE EFFECTS OF PERFECT GAS PARAMETERS ON GAS TURBINE PERFORMANCE. A. G. Hammitt. Princeton U. Dept. Aero. Eng. Rep. 500 (AFOSR TN 60-225), Dec., 1959. 26 pp. Study of a perfect gas considering three parameters to characterize its properties: specific heat ratio, speed of sound, and viscosity. The effects of specific heat ratio and speed of sound are more significant unless the viscosity exhibits very large variations. A gas of low specific heat ratio and high speed of sound is advantageous for the operation of the heat exchangers while a high specific heat ratio and low speed of sound makes the turbomachinery simpler. The best gas would depend on the relative cost of the different types of equipment.

Rocket

APPROXIMATE THEORETICAL PERFORMANCE EVALUATION FOR A DIVERGING ROCKET. T. A. Jacobs, S. S. Penner, G. Gill, and E. F. Eckel. Astronautica Acta, Fasc. 2-3, 1960, pp. 151-158. Application of a simplified combustion model, which is motivated by available performance studies on the diverging rocket reactor, as a basis for an engine performance evaluation. Comparison with conventional rocket configurations shows that an upper performance limit for the diverging reactor is comparable to performance estimates for engines using an adiabatic working cycle. Development of the diverging reactor for engine applications may, however, offer some ad-

vantages for very hot, high-energy propellant systems.

LES FUSEES A LITHERGOL OU FUSEES HYBRIDES. A. Moutet and M. Barrère. La Recherche Aéronautique, Mar.-Apr., 1960, pp. 23-35. In French. Study of various possible combinations when using propellants composed of two phases, one liquid and the other solid, and description of the operating principles of rockets using such a propellant. A simple theory is developed which leads to the determination of main characteristic parameters of these rockets. Some experimental results confirming theoretical data are presented, and the main advantages of such a family of engines are also analyzed.

PROPELLERS

A WIND-TUNNEL INVESTIGATION OF THREE PROPELLERS THROUGH AN ANGLE-OF-ATTACK RANGE FROM 0° TO 85°. P. F. Yaggy and V. L. Rogallo. US, NASA TN D-318, May, 1960. 81 pp. OTS, $2.25. Study of propeller performance, including in-plane forces and out-of-plane moments, for heavily loaded, higher solidity propellers operating at low advance ratios and high tilt angles that would be typical in the operation of VTOL/STOL aircraft. The propellers differed widely in planform and included one with flapping hinges. The results of the investigation revealed that, for all three propellers, similar variations in the forces and moments with thrust-axis angle of attack and advance ratio were present. Further, the thrust and power were nearly constant and in-plane forces and out-of-plane moments increased approximately linearly over large ranges of thrust-axis angle of attack for constant blade angles and effective advance ratios.

RESEARCH, RESEARCH FACILITIES

Wind Tunnels

BALLISTIC RESEARCH LABORATORIES' NEW HYPERSONIC TUNNEL. J. Sternberg. US, BRL Rep. 1076, Jan., 1960. 24 pp. Description of a hypersonic wind tunnel designed to operate from Mach number 5 to 10, and capable of continuous flow, variable density operation. Tunnel air can be heated to a maximum temperature of 2,000°R., using a combustion heater and an electric heater arranged in series. The role of such a tunnel in finding solutions to the complications of hypersonic flight at high altitudes is discussed.

A DIRECT METHOD OF MEASURING DENSITY BEHIND SHOCK WAVES. D. B. Sleator and M. R. Lewis. US, BRL Rep. 1087, Dec., 1959. 21 pp. Presentation of a method for measuring velocity and density behind a shock wave which uses the N-like slip region resulting from the interaction of the shock and a small disturbance. The velocity of the slip region along the axis of the shock tube is shown to be the flow velocity. A description of the interaction of a shock wave and a small disturbance is given. Still and streak schlieren photographs and an interferogram of the phenomenon are presented along with a plot of experimental results versus theory showing an error of about 1%.

STUDYING HYPERSONIC FLIGHT IN THE SHOCK TUNNEL. Abraham Hertzberg and Ch. E. Wittliff. IAS Natl. Summer Meeting, Los Angeles, June 28-July 1, 1960, Paper 60-67. Members, $0.50; nonmembers, $1.00. 102 pp. 89 refs. Review of the development of the shock tunnel, discussion of its present capabilities, and outline of future prospects. The performance capabilities of the hypersonic shock tunnel relative to simulating flight conditions for various hypersonic vehicles are shown. Techniques of partial simulation are discussed for those flight regimes where full simulation cannot be achieved. The future development of the shock tunnel is considered in detail. Particular emphasis is placed on the applicability of the shock tunnel to investigating hypersonic rarefied-gas flows. The requirements of large-diameter nozzles in this region of hypersonic flows are indicated. The advantages of nearly full-scale testing are discussed as they pertain to those hypersonic flow phenomena not amenable to scale-model experiments.

STRUCTURES

Bars & Rods

THE STRESSES IN AN ELASTO-PLASTIC BAR SUBJECTED TO A SUDDEN CHANGE OF SURFACE TEMPERATURE. E. W. Parkes. Stanford U. Dept. Aero. Eng. SUDAER 89 (AFOSR TN 60-321), Jan., 1960. 20 pp. Presentation of an analysis for the stress history in an elastoplastic bar subjected to a sudden change of surface temperature. The type of behavior is found to depend on the ratio of thermal strain (αV) to yield strain (σ_y/E). For $E\alpha V/\sigma_y < 1$, the stresses are entirely elastic. For $1 < E\alpha V/\sigma_y < 2.04$ there are two transient zones of compressive yielding. For $2.04 < E\alpha V/\sigma_y < 4.4$ there are two transient zones of compressive yielding and two enduring zones of tensile yield. For $E\alpha V/\sigma_y > 4.4$ there are two transient zones of compressive yielding, one transient zone of tensile yielding, and two enduring zones of tensile yielding. The investigation is restricted to the range $0 \leq E\alpha V/\sigma_y \leq 5$ and the particular case $E\alpha V/\sigma_y \to \infty$. Detailed solutions are given for $E\alpha V/\sigma_y = 1, 2, 3, 4, 5,$ and ∞.

Beams & Columns

THE PHENOMENON OF CHANGE IN BUCKLE PATTERN IN ELASTIC STRUCTURES. Manuel Stein. US, NASA TR R-39, 1959. 9 pp. GPO, $0.30. Analysis of a model three-element column connected by linear torsional springs and laterally restrained by nonlinear extensional springs. The analysis indicates the action of change in buckle pattern for two types of loading. The results indicate that, for initially perfect specimens, intersections between curves for the various equilibrium configurations lead to changes in buckle patterns. The load at which a change in buckle pattern occurs is shown to be independent of the

type of loading, but the manner of change does depend on the type of loading. The change can be continuous or discontinuous, depending on the structure and on the type of loading.

Cylinders & Shells

GENERAL RESEARCH IN FLIGHT SCIENCES - MECHANICS OF DEFORMABLE BODIES. I - BUCKLING OF A CYLINDRICAL SHELL OF ARBITRARY LENGTH UNDER A CIRCUMFERENTIAL BAND OF PRESSURE. B. O. Almroth and D. O. Brush. Lockheed Aircraft Missiles & Space Div., vol. II, TR LMSD-288139, Jan., 1960. 39 pp. Analysis made for the determination of the allowable loads in motor cases and other thin-walled structures during handling and storage. The method uses a stability criterion based on the principle of minimum potential energy. The Rayleigh-Ritz procedure is used to expand the displacement components in trigonometric series. Results are presented in the form of graphs showing buckling pressure as a function of the ratios: cylinder radius/thickness, cylinder length/radius, and pressure bandwidth/cylinder length. It is found that, except for wide pressure bands, the buckling pressure is inversely proportional to bandwidth.

GENERAL RESEARCH IN FLIGHT SCIENCES - MECHANICS OF DEFORMABLE BODIES. II - PREBUCKLING DEFLECTION STRESSES IN A CIRCULAR CYLINDER SUBJECTED TO A SADDLE-TYPE LOAD. B. O. Almroth. Lockheed Aircraft Missiles & Space Div., vol. II, TR LMSD-288139, Jan., 1960. 32 pp. Presentation of a method for calculating prebuckling deflections in a cylinder of arbitrary length subjected to an external pressure over a certain part of its length. The analysis is based on elastic small deflection theory. Simple approximate formulas are given for lateral displacements, direct membrane stresses, and bending stresses.

GENERAL RESEARCH IN FLIGHT SCIENCES - MECHANICS OF DEFORMABLE BODIES. IV - LARGE DEFLECTION AND BUCKLING ANALYSIS OF CIRCULAR CYLINDRICAL SHELLS. D. O. Brush. Lockheed Aircraft Missiles & Space Div., vol. II, TR LMSD-288139, Jan., 1960. 24 pp. 14 refs. Application of a variational procedure to derive equilibrium equations for the infinitesimal buckling of cylindrical shells. The nonlinear strain-displacement relations are based on a theory by Novozhilov for moderately large shell deformations. It is shown that, for a large number of circumferential waves in a harmonic analysis of the displacement components, these relations reduce to those used by von Kármán and Tsien in their large-deflection analysis of the axially loaded cylinder. It is also shown that the nonlinear strain-energy expression used by von Kármán and Tsien is also the strain-energy expression underlying the Donnell equations for infinitesimal buckling.

GENERAL RESEARCH IN FLIGHT SCIENCES - MECHANICS OF DEFORMABLE BODIES. V - APPROXIMATE BUCKLING LOADS BY ENERGY METHODS. D. O. Brush. Lockheed Aircraft Missiles & Space Div., vol. II, TR LMSD-288139, Jan., 1960. 20 pp. Presentation of a systematic approximate method using energy analysis for determination of buckling loads in thin shells. The method is of general applicability to static, conservative systems. Emphasis is placed on the underlying geometrical relationships and on the distinction between stationary and minimum potential energy. Application of this method is illustrated by a specific example - the buckling of a circular ring subjected to uniform external pressure. Correspondence between terms in this method of analysis and the method used by Timoshenko is illustrated.

GENERAL RESEARCH IN FLIGHT SCIENCES - MECHANICS OF DEFORMABLE BODIES. VII - STRESSES IN SPHERICAL PRESSURE VESSELS. O. Hoffman. Lockheed Aircraft Missiles & Space Div., vol. II, TR LMSD-288139, Jan., 1960. 21 pp. Study of the relationships for stresses and deformations in thin-walled spherical pressure vessels subjected to uniform internal pressure. Some applications to practical design problems are shown, including discontinuity stresses due to the presence of an elastic reinforcing ring and those occurring at welded joints because of manufacturing inaccuracies.

GENERAL RESEARCH IN FLIGHT SCIENCES - MECHANICS OF DEFORMABLE BODIES. VIII - A STATISTICAL ANALYSIS OF AXIALLY LOADED CYLINDER BUCKLING DATA. E. V. Pittner. Lockheed Aircraft Missiles & Space Div., vol. II, TR LMSD-288139, Jan., 1960. 33 pp. 17 refs. Correlation of experimental data with the shell radius/thickness ratio. Using the method of least squares and consulting tables of normal probability functions for small samples, the statistical mean of the buckling stress and its probability limits are determined for several r/t ranges from which design curves are developed. In addition to the statistical mean of the buckling stress for unpressurized cylindrical shells under axial compression, estimates are given for 90%, 95%, 99%, and 1% failure-probability curves.

GENERAL RESEARCH IN FLIGHT SCIENCES - MECHANICS OF DEFORMABLE BODIES. X - ELASTO-PLASTIC ANALYSIS OF SHELLS OF REVOLUTION SUBJECTED TO HEATING AND EXTERNAL LOADS. E. Y. W. Tsui and P. Stern. Lockheed Aircraft Missiles & Space Div., vol. II, TR LMSD-288139, Jan., 1960. 25 pp. Presentation of solutions for shells of revolution subjected to rotationally symmetrical temperature gradients, surface tractions, and edge forces. The analysis is based on the theory of thin shells and the general assumptions of plasticity with the Huber-Mises-Hencky yield condition. The thickness of shell may vary in the meridional direction. To provide for the plastic deformations under high temperature and/or external loads, a nonlinear stress-strain relation is introduced. The problem is solved by the Ritz method in conjunction with a

procedure of successive approximations for the determination of plastic strains.

BUCKLING OF CONICAL SHELLS UNDER EXTERNAL PRESSURE AND THERMAL STRESSES. Josef Singer and N. J. Hoff. Technion Res. Devel. Found., Haifa, Final TR (AFOSR TR 59-203), Dec., 1959. 82 pp. 21 refs. Derivation of simplified differential equations governing the deformations of deep thin circular conical shells subjected to arbitrary loads and arbitrary temperature distributions by the principle of the minimum total potential energy. An asymptotic solution of these simplified equations is then obtained for a truncated conical shell subjected to an axisymmetrical temperature distribution. The equations are then extended to include problems of elastic stability. These are solved for loading under lateral and under hydrostatic pressure in the presence of slightly relaxed boundary conditions for the u and v displacements; for the w (radial) displacements, the usual conditions of simple support are rigorously enforced. The solution is valid for thin shells having small cone angles which buckle with a large number of circumferential waves. The same method of solution is then applied to the thermal buckling problem of truncated conical shells subjected to axisymmetric temperature distributions.

BUCKLING OF A THIN CIRCULAR CYLINDRICAL SHELL HEATED ALONG AN AXIAL STRIP. D. W. Hill. Stanford U. Dept. Aero. Eng. SUDAER 88 (AFOSR TN 59-1250), Dec., 1959. 91 pp. 19 refs. Analysis considering a thin circular cylindrical shell heated along a narrow strip in the axial direction. The problem is solved using the Ritz method, assuming for the displacements Fourier series modified by a shape factor chosen to magnify the solution in the vicinity of the heated strip. In the analysis of the stress distribution, the cylinder is assumed to be simply supported on its ends so that the radial and circumferential displacements there are zero, but the axial displacements and end rotations are not restricted. Expressions are given relating the physical parameters of the cylinder, the temperature distribution, and the magnitude of the temperature causing buckling. Experimental results are presented for buckling tests on eleven cylinders, which show a reasonable agreement with theoretical calculations. Courant's maximum-minimum principle is used to establish that the buckling stress for a cylinder under uniform axial compression is a lower bound for all other cases of axial loading, provided that the buckling stress is taken as the maximum compressive stress on the cross section.

Elasticity & Plasticity

A STUDY OF THE NONLINEAR THEORY OF CREEP. Chao Tsu-wu. Scientia Sinica, May, 1960, pp. 652-663. 18 refs. Derivation of a new basic equation for creep which does not contain the variable "t" in an explicit form and express the property that the creep strain is partially recoverable and its velocity approaches a constant value in the second stage under a constant stress. In addition, the basic equation gives a partially recoverable creep strain with a continuously decreasing velocity for those materials, the mechanical properties of which change with age. Finally, the problems of relaxation and pure bending are investigated.

Fatigue

GENERAL RESEARCH IN FLIGHT SCIENCES - MECHANICS OF DEFORMABLE BODIES. XIV - STRESSES GENERATED BY SUDDENLY INTRODUCING A MOVING CRACK INTO A STRETCHED ELASTIC SHEET. B. R. Baker. Lockheed Aircraft Missiles & Space Div., vol. II, TR LMSD-288139, Jan., 1960. 67 pp. 12 refs. Analysis considering the problem of a growing crack suddenly appearing in a stretched elastic plate. Transform methods are used to obtain the Wiener-Hopf equation which is solved by standard techniques. Procedures for obtaining stresses at any point in the plane are outlined, and real integrals are presented for the transverse stress ahead of the crack and for the vertical displacement of the crack surface. It is found that the speed of Rayleigh waves plays an important role; for sub-Rayleigh crack speeds, the transverse stress has a tensile singularity; for super-Rayleigh speeds, the singularity is compressive.

Sandwich Construction

SANDWICH CONSTRUCTION. II - CORRELATION AND EXTENSION OF EXISTING THEORY OF FLAT PANELS SUBJECTED TO LENGTHWISE COMPRESSION. W. G. Heath. Aircraft Eng., Aug., 1960, pp. 230-235. Development of expressions for determining the cross-sectional dimensions of the lightest panel, the panel width and loading being given. Two types of optimum panel are discussed: (a) the core being chosen from an infinite range of densities, and (b) the core having fixed properties. In the case of metal honeycomb of similar material to the faces, it is shown that type (a) is often impossible to achieve in practice, owing to the impractically small thickness of the ribbon required for the manufacture of the optimum core.

INITIALLY WARPED SANDWICH PANEL UNDER COMBINED LOADINGS. C. C. Chang and B. T. Fang. J. Aerospace Sci., Oct., 1960, pp. 779-787. 13 refs. Derivation of differential equations, based on the small deflection theory, for the elastic bending of an orthotropic weak-core sandwich panel with small initial warping. The applied loads consist of arbitrarily distributed transverse loads and eccentrically applied edge loads and/or edge moments. For the case of a simply supported rectangular panel, solutions of the differential equations are obtained in the form of double Fourier series. As a practical example, numerical values of the maximum stresses and deflections for a square sandwich panel are calculated and presented in graphical form.

Thermal Stress

THE ELASTIC STRESSES AND DEFORMATIONS PRODUCED IN A SEMI-INFINITE ELASTIC SOLID

BY A POINT SOURCE OF HEAT BENEATH ITS FREE SURFACE. Liu Hsien-chih. Scientia Sinica, May, 1960, pp. 604-651. 13 refs. Analysis of a model which corresponds to a logarithmic source of heat beneath the free surface of a semi-infinite solid plate. The analysis is divided into two parts: one for the normal surface load, and the other for the shear load. Numerical solutions are presented for the axial, radial, and tangential stresses, as well as shear stress parallel to the free surface, and for the radial and axial displacements. The stresses and displacements are presented graphically as functions of the axially symmetric and radial coordinates for values of the distance of the heat source below the free surface of 5, 10, and 15 cm.

EFFECTS OF REPEATED THERMAL LOADING. E. W. Parkes. Aircraft Eng., Aug., 1960, pp. 222-229. Analysis of a simple redundant structure to determine the influence of the yield stress/temperature relation on its behavior. The range and periodic time of the temperature cycle are included as subsidiary variables. It is found that improving the strength of the material at elevated temperatures may have the undesirable effect of hastening incremental collapse of the structure, and that the most rapid incremental collapse is not necessarily associated with maximum values for the range and periodic time of the temperature cycle. It is also found that the common assumption that the strength of the material is independent of temperature, may in some circumstances be ambiguous, since there may be a sudden discontinuity in behavior between a structure made from a material having a slight negative strength/temperature gradient and one made from a material having a slight positive gradient.

Wings

PROCEDURES FOR INCLUDING TEMPERATURE EFFECTS IN STRUCTURAL ANALYSIS OF ELASTIC WINGS. V - CORRELATION OF ANALYSIS WITH STATIC TESTS OF TWO LARGE DEFLECTION WING MODELS. H. A. Balmer and K. A. Foss. USAF WADC TR 57-754, Pt. V, Jan., 1960. 24 pp. Comparison of static tests with computed deflections and stresses. The test results are obtained by simulating distributed air loads and reaction loads on full span models through the use of a whiffletree arrangement. The computed results were obtained on an IBM 704 digital computer in terms of assumed modes through the use of a variational statement of the von Kármán large-deflection plate equations. Within the limitations of the experimental procedure and the computer program method, the correlations between experiment and theory show reasonable agreement for both deflections and stresses.

THERMODYNAMICS

Combustion

DETONATION INDUCTION DISTANCES IN COMBUSTIBLE GASEOUS MIXTURES AT ATMOSPHERIC AND ELEVATED INITIAL PRESSURES. IV - HYDROGEN-NITRIC OXIDE. V - HYDROGEN-OXYGEN-DILUENT. VI - THEORETICAL ANALYSIS. L. E. Bollinger, M. C. Fong, and Rudolph Edse. USAF WADC TR 58-591, Pt. II, Aug., 1959. 78 pp. 19 refs. Investigation of some fuel-oxidizer mixtures for various diluent concentrations at initial pressures of 1 and 5 atm. Nitrogen, helium, argon, and carbon dioxide were the individual diluents which were added to a stoichiometric mixture of hydrogen and oxygen. Addition of any of the diluents caused an increase in the detonation induction distance by varying amounts. A theoretical analysis of the formation of a detonation wave is made, and a correlation function is found which relates the detonation induction distance to the Reynolds number, the normal burning velocity of the mixture, the sonic velocity of the unburned gas, and the adiabatic combustion temperature of the given mixtures.

FLAME STABILIZATION ON A POROUS PLATE. A. Q. Eschenroeder. ARS J., Aug., 1960, pp. 754-758. 18 refs. Investigation of the position and stability of the flame in a boundary layer with uniform mixture injection from a porous flat plate parallel to a uniform air stream. Propane-air flames were observed over a free stream velocity range of 10 to 42 ft. per sec. and a range of mass equivalence ratios for the injected mixture from 1.09 to 4.76. Both the average and time variant distances from the leading edge to the beginning of the flame are measured at various free stream air mass fluxes, injection mass fluxes, and injection mixture compositions. A correlation of nondimensional flameholding distance with mixture composition is obtained.

VTOL & STOL

SOME BRITISH RESEARCH ON THE BASIC AERODYNAMICS OF POWERED LIFT SYSTEMS. John Williams. RAeS J., July, 1960, pp. 413-432; Discussion, pp. 433-437. 67 refs. Discussion of recent RAE and NPL research on the aerodynamics of direct jet lift (turbojet and turbofan), propeller lift (tilt-wing and deflected slipstream), jet flaps, and boundary layer control (blowing and suction). A survey is made of the present state of knowledge in relation to VTOL and STOL aircraft applications and some major aerodynamic problems which need further study. Static model tests, wind-tunnel experiments, and theoretical investigations are covered.

PROBLEMES DE LA SURFACE PORTANTE ANNULAIRE TRAITES PAR LA METHODE DES ANALOGIES RHEOELECTRIQUES. Gérard Hacques. France, Min. de l'Air PST 358, 1960. 123 pp. 16 refs. SDIT, 2 Av. Porte-d'Issy, Paris 15, NF 27.00. In French. Application, within the lifting surface theory, of the method of rheoelectric analogy to study the theoretical performance of the annular wing. Various aerodynamic effects due to the variation of geometric parameters of the wing and the wing profile are analyzed: annular lifting system - wing in axial flow (conicity, curvature, and profile thickness), cylindrical wing in three-dimensional flow (lift, pressures, moments). The rotation of a propeller and the presence of a central body in the wing are also studied. A comparison with available theoretical and experimental results shows good agreement.

Comparative EEG and Psychometric Data for 825 French Naval Pilots and 511 Control Subjects of the Same Age. H. Gastaut, M. C. Lee, and P. Laboureur. (*Aero Med. Assoc. 30th Annual Meeting, Los Angeles, Apr. 29, 1959.*) *Aerospace Med.*, July, 1960, pp. 547–552. 15 refs.

The Incidence of Hypoglycemia in Flight. E. R. Taylor. (*Aero. Med. Assoc. 30th Annual Meeting, Los Angeles, Apr. 29, 1959.*) *Aerospace Med.*, June, 1960, pp. 462–467. Investigation of blood sugar level changes in normal pilot population and of the in-flight incidence of hypoglycemia. A correlation is made between diet, especially the composition of the breakfast, and the decrease in blood glucose level.

Respiratory and Circulatory Response of the Hypothermic Animal to Carbon Dioxide Stress. F. G. Hall and John Salzano. *USAF WADD TR 60-82*, Mar., 1960. 12 pp. 10 refs.

Avoiding the Radiation Belt. A. E. Slater. (*Space Med. Symposium, London, Oct. 16, 17, 1958.*) *Brit. Interpl. Soc. J.*, May-June, 1960, pp. 321–323. Discussion of the hazards of the van Allen radiation belts. It is pointed out that once every day the ecliptic is inclined 35° to the magnetic equator, thus providing the possibility of making interplanetary journeys without passing through the dangerous zone. Conditions for the lunar voyage are indicated.

Telemetering of Intraenteric Pressure in Man by an Externally Energized Wireless Capsule. J. T. Farrar, Carl Berkley, and V. K. Zworykin. *Science*, June 17, 1960, p. 1814. Discussion of a capsule capable of detecting physiologic pressure variations within the esophagus, stomach, small intestine, or colon. The pressure records are similar to those obtained by other sensing devices.

Human Engineering

Human Factors in a Space Cabin, with Special Reference to Weight and Economy. L. G. C. E. Pugh. (*Space Med. Symposium, London, Oct. 16, 17, 1958.*) *Brit. Interpl. Soc. J.*, May-June, 1960, pp. 317–319. Study of human problems in space travel, considered in the light of experience of extreme conditions of hypoxia and climatic stress on Mount Everest. Methods of saving mass by (1) reduction of the air pressure in a space capsule, (2) choice of lightweight personnel, and (3) economy of food and fluid, are discussed.

Impairment of Human Performance in Control. K. F. Jackson. (*Space Med. Symposium, London, Oct. 16, 17, 1958.*) *Brit. Interpl. Soc. J.*, May-June, 1960, pp. 301–303. Discussion of two experiments investigating the factors which affect the quantity and quality of a pilot's work.

Man-Machine Tracking Performance with Short-Period Oscillatory Control System Transients. F. A. Muckler. *USAF WADD TR 60-3*, Jan., 1960. 14 pp. 14 refs.

The Man-Machine System in Space Vehicles. G. W. Hoover. (*Space Med. Symposium, London, Oct. 16, 17, 1958.*) *Brit. Interpl. Soc. J.*, May-June, 1960, pp. 304–310. Discussion of an integrated approach to the determination of the requirements for a closed, decision-making environment for the astronaut. The development of the U.S. Army-Navy Instrumentation Program for providing equipment embodying optimum data presentation and control for the man-machine system is outlined, and the application of the concepts to the spaceship is noted.

Chemistry

General Research in Flight Sciences—Fluid Mechanics. VIII—Comparative Studies of Vibrational Relaxation in Nitric Oxide. P. R. Monson, J. J. Allport, and F. A. Robben. *Lockheed Aircraft Missiles & Space Div., vol. I, Pt. II, TR LMSD-288139*, Jan., 1959–Jan., 1960. 24 pp. Application of ultraviolet absorption and infrared emission techniques to follow the vibrational relaxation of nitric oxide after shock heating in a temperature range from 450°K. to 1,300°K. The infrared technique yields a vibrational de-excitation probability, P_{10}, an order of magnitude or more below the ultraviolet results.

Research on a New Class of Inorganic Molecules Consisting Basically of Sulfur and Nitrogen. M. E. Cohen, R. A. Kent, A. G. MacDiarmid, and N. H. Marcantonio. *USAF WADD TR 60-169*, Apr., 1960. 17 pp. 13 refs.

Recombination of Atoms at Surfaces. VII—Hydrogen Atoms at Silica and Other Similar Surfaces. M. Green, K. R. Jennings, J. W. Linnett, and D. Schofield. *Oxford U. Inorganic Chem. Lab. Rep.* (*AFOSR TN 59-869*), Feb., 1960. 27 pp. 22 refs.

Computers

The Digital Computer as a Tool for Design Engineers. Benjamin Mittman and R. B. Wise. *Elec. Mfg.*, Aug., 1960, pp. 116–123, 129. 67 refs. Discussion of the methods of analysis and synthesis for using computing machines in design, including practical illustrative examples.

Digital Simulator Checks Space Communications Design. D. R. J. White. (*IRE 6th*

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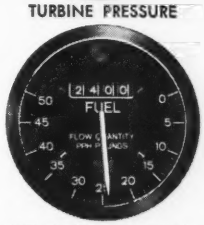

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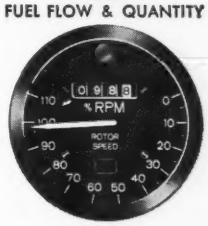

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Annual East Coast Conf. on Aero. & Navigational Electr., Baltimore, Oct., 1959.) Space/Aeronautics, July, 1960, pp. 125–129. Discussion of the use of digital computer simulation in the design and evaluation of complex electronic systems. A computer program covering some 100 variables and many theoretical and empirical relationships that nevertheless makes for quick analysis of trial designs is presented.

General Research in Flight Sciences—Mathematics and Statistics. III—Word-Correlation Study. R. P. Mitchell. *Lockheed Aircraft Missiles & Space Div., rpt. IV, TR LMSD-288139*, Jan., 1959–Jan., 1960. 25 pp. Presentation of a method of syntactic analysis of declarative English sentences, proposed by Bar-Hillel and Lambeck, operationally extended in such a manner that the product of the analysis is a machine retrieval language.

A Method of Binary Multiplication, and Its Application in a Parallel Multiplier. J. K. Moore. *Gt. Brit., RAE TN G. W. 541*, Mar., 1960. 17 pp.

Some Methods of Parallel Addition, and Their Application to Multiplication Processes. A. P. M. Cunningham and J. K. Moore. *Gt. Brit., RAE TN G.W. 540*, Mar., 1960. 16 pp.

Control Theory

Analysis and Computer Study of an Adaptive Control System. D. A. Dawson. *Canada, NRC Div. Mech. Eng. Rep. MK-4*, Sept., 1959. 84 pp. Analysis of an adaptive or self-optimizing control system formulated on an economic criterion—i.e., the system is controlled in such a manner as to minimize the cost.

How to Analyze Control Systems with Time Lag. Y. L. Luke. *Electronic Ind.*, July, 1960, pp. 75–78. Presentation of a numerical procedure for determining the degree of stability which produces an accurate location of the zeros of the characteristic equation on the complex plane by replacing the exponential in the characteristic equation with an approximation and solving polynomials.

Shannon's Theory and Feedback Systems. S. S. L. Chang. *(ASME Instruments & Regulators Conf., Cleveland, Mar. 29–Apr. 2, 1959, Paper 59-IRD-12.) ASME Trans., Ser. D - BE*, Mar., 1960, pp. 46–50. 14 refs. Discussion of feedback as a means of realizing the Shannon-predicted errorless capacity of a noisy communications channel, and study of Shannon's information theory as a guide for rating feedback control systems as well as for selecting system components. Included topics are calculations of required information capacities for control systems from input characteristics and fidelity requirements, required information capacities of system components, and calculation of information capacities of system components from saturation limits, threshold levels, and transfer functions.

Static Relays: How Well Do They Work, How Can You Use Them? R. F. Blake. *Space/Aeronautics*, July, 1960, pp. 143, 144, 146–153 (ff.). Discussion of the characteristics, applications, and competitiveness of the static (no-moving-part) relay.

The Design and Analysis of a Servovalve with Flow Feedback. E. Bahniuk and S.-Y. Lee. *(ASME Instruments & Regulators Conf., Cleveland, Mar. 29–Apr. 2, 1959, Paper 59-IRD-3.) ASME Trans., Ser. D - BE*, Mar., 1960, pp. 73–80. Presentation of a new approach to the servovalve design, using a flow signal for flow rate control instead of valve position in the feedback loop, thus eliminating the necessity of a high precision valve, prolonging the life expectancy of the valve, and minimizing the effect of load variation, as well as supply pressure variation. Dynamic analysis and test results of the flowmeter and the complete valve are given.

Dynamic Pressure Feedback. *Aircraft Eng.*, June, 1960, pp. 171–176. Discussion of the performance limitations imposed by a particular load when a conventional flow control valve is utilized in a valve-actuator component. It is shown that the load versus flow characteristics of the forward loop can be modified advantageously. Various techniques utilized in the past for this purpose, such as controlled actuator by-pass leakage and structural feedback, are compared with a new technique called dynamic pressure feedback. This technique involves only a modification of servo valve component and utilizes for feedback purposes the inherently high load forces developed as piston differential pressures.

Bang-Bang Versus Linear Control of a Second-Order Rate-Type Servomotor. P. F. Meyfarth. *(ASME Instruments & Regulators Conf., Cleveland, Mar. 29–Apr. 2, 1959, Paper 59-IRD-13.) ASME Trans., Ser. D - BE*, Mar., 1960, pp. 66–72. USAF-supported research.

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Appareillage d'Asservissement Permettant d'Exciter un Système de Fréquence Variable dans le Temps. A. Duchêne. *La Recherche Aéronautique*, Jan.-Feb., 1960, pp. 37–39. In French. Description of the basic principles and operation of a servosystem modified to study the evolution of resonance frequencies in missiles under high accelerations.

Documentation

Special Issue: Research in Documentation—A Symposium. *Franklin Inst. J.*, July, 1960, pp. 1–50. 22 refs. *Partial Contents:* Semi-Automatic Indexing and Encoding, Julius Frome. Metallurgical Documentation from Research to Practice, M. R. Hyslop. Storing Numerical Values in an Inverted File for Mechanized Information Retrieval, D. D. Andrews. Machine Literature Searching in Science, Allen Kent.

Education & Training

Boeing 707 Flight Crew Training Experience. J. R. Gannett. *Soc. Exp. Test Pilots Quart. Rev.*, Spring, 1960, pp. 22–25. Discussion of the flight crew training program, including cooperation of manufacturer and airline, phases of the training course, and factors affecting the length of time necessary to check out a pilot.

Factorial Structure and Validity of Naval Aviation Selector Variables. R. K. Ambler, J. T. Bair, and R. J. Wherry, Jr. *(Aerospace Med. Assoc. 30th Annual Meeting, Los Angeles, Apr. 29, 1959.) Aerospace Med.*, June, 1960, pp. 456–461. Investigation performed on 790 naval aviation cadets and aviation officer candidates to determine the effectiveness of the Aviation Score Sheet as an aid in summarizing and evaluating attributes, other than physical, that are considered in screening candidates.

A Display Unit for a Flight Simulator. A. G. Barnes and W. F. Coulshed. *Electronic Eng.*, July, 1960, pp. 402–407. Discussion of the design limitations and electronic techniques used in generating a visual representation of the ground on a cathode-ray tube in the simulator cockpit. A description of the display in use is included.

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Microwaves—Principles and Devices. Milton Tenzer and J. P. Agrios. *Elec. Mfg., Sci. & Eng. Ser.*, Aug., 1960, pp. 89–112. 11 refs. Survey covering the basic concepts, electromagnetic wave behavior, guided propagation, and application of principles to microwave components.

The Role of Space Charge Waves in Modern Microwave Devices. I. G. D. Sims and I. M. Stephenson. *Electronic Eng.*, July, 1960, pp. 408–412. Discussion of the fundamental characteristics of space charge wave propagation considering the waves also in terms of a transmission line analogy.

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Amplifiers

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The Design and Performance of Quadraloop Telemetry and Control Antennas for the Aerobee Hi and Spaerobee Rockets. D. G. Henry. *New Mexico State U. Phys. Sci. Lab. Sci. Rep. 3 (AFCRC TN 60-280)*, Feb. 22, 1960. 154 pp.

400 Mc/Sec Cutoff Notch Antenna Aerobee Hi. D. G. Henry. *New Mexico State U. Phys. Sci. Lab. Sci. Rep. 4 (AFCRC TN 60-295)*, Mar. 2, 1960. 18 pp.

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Transient Phenomena During Amplitude and Frequency Modulation in Some Special Passive Circuits. E. Henze. *(Arch. elek. Übertr.*, No. 9, 1955, pp. 326–338.) *Gt. Brit., MA TIL/T5010*, Dec., 1959. 24 pp. 12 refs. Translation.

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Designing for Miniaturization. I. D. A. Ladine, R. L. Spencer, and G. A. Ohlson *Librascope Tech. Rev.*, Spring, 1960, pp. 26–31. Discussion of the design procedure and the characteristics of a transistor servoamplifier. Miniature servo applications, including application problems, are considered.

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The Interpretation of Characteristics and of Fundamental Equations of the Electromagnetic Field. G. Fodor. *Periodica Polytech., Elec. Eng. Ser.*, No. 3, 1959, pp. 197–215. Discussion of the two methods of building up Maxwell's equations, presenting the conclusion that in practice, the applications of both methods have their limitations and that, therefore, the course of the variation of the electromagnetic field should be taken into account in computing energy.

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Calculating Bandwidths for Matching Networks. H. B. Yin. *Electronic Ind.*, July, 1960, pp. 70–74. Presentation of a new set of formulas for $2(L)$-, $3(T$ or $\pi)$-, and 4-element matching networks which (unlike the Smith Chart in certain cases) do not introduce inaccuracies. The correction factor for loss of the inductor is also presented.

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the control center, and the cost of the project are presented.

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On a Generalization of the Index Notation for Absolute Tensors of Arbitrary Order. E. H. Brown. *J. Res., Sect. B - MMP*, Apr.-June, 1960, pp. 99–103. Presentation of a generalized vector index notation which facilitates the study of properties of tensors regardless of order and variance of components. The notation also suggests treatment of order transformations of tensors.

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Mechanics

On a Dynamical Saint Venant Principle. B. A. Boley. (*ASME Annual Meeting, Atlantic City, Nov. 29–Dec. 4, 1959, Paper 59-A-61.*) *ASME Trans., Ser. E - AM*, Mar., 1960, pp. 74–78. Navy-sponsored investigation of the dynamic behavior of a simple mechanical model composed of two Timoshenko beams connected by springs. The accuracy of a quasi-static solution and of Saint Venant's principle is studied for various rates of load application.

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Classical Normal Modes in Damped Linear Dynamic Systems. T. K. Caughey. (*ASME Annual Meeting, Atlantic City, Nov. 29–Dec. 4, 1959, Paper 59-A-62.*) *ASME Trans., Ser. E - AM*, June, 1960, pp. 269–271. Presentation of an analysis of the conditions under which a damped linear system possesses classical normal modes. It is shown that a necessary and sufficient condition for the existence of classical normal modes is that the damping matrix be diagonalized by the same transformation that uncouples the undamped systems. Sufficient, though not necessary, conditions on the damping matrix are developed, and it is shown that Rayleigh's solution is a special case of the presented theory.

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Theory of the Motion of a Body with Cavities Partly Filled with a Liquid. D. E. Okhotsimskii. (*Prikl. Mat. i Mekh.*, Jan.-Feb., 1956, pp. 3–20.) *U.S., NASA TT F-33*, May, 1960. 21 pp. OTS, $0.75. Translation. Study of forces associated with small motion of a circular cylinder containing fluid with a free surface. For impulsive motion, simple harmonic motion, and motion just beginning, it is shown that the body of fluid possesses inertial characteristics similar to the mass, moment of inertia, and center of mass of a rigid body. Suggestions are made for establishing the general equations of motion for the system.

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Calculations of Atmospheric Infrared Radiation as Seen from a Meteorological Satellite. S. M. Greenfield and W. W. Kellogg. *J. Meteorology*, June, 1960, pp. 283–290. 24 refs. USAF-sponsored presentation of sample calculations of the emission by the atmospheric water vapor in three wavelength intervals. It is shown that for very strong absorption by water vapor (as at 6.0μ) and the United States humidity distribution, the upward emission originates mostly in the stratosphere, whereas for weaker absorption or lower stratospheric humidities, the upward emission comes mostly from below the tropopause.

An Airborne Cloud-Drop-Size Distribution Meter. D. P. Keily and S. G. Millen. *J. Meteorology*, June, 1960, pp. 349–356. 20 refs. USAF-supported research.

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The Motion and Erosion of Convective-Storms in Severe Vertical Wind Shear. Walter Hitschfeld. *J. Meteorology*, June, 1960, pp. 270–282. 14 refs. USAF-sponsored investigation of well developed thunderstorms, observed by CAPPI-equipped radar to remain upright even in the presence of severe wind shear. Vertical motion and storm erosion are used to explain how active cores of large storms remain nearly vertical almost independently of the wind shear.

Upper Air Research

Présent et Avenir de Véronique. Jean Corbeau. *Tech. & Sci. Aéronautiques*, Nov.-Dec., 1959, pp. 369–372. In French. Survey covering the project Veronique, including the development, performance, and launchings of the sounding rocket designed for ionospheric research.

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Optimal Composition and Deployment of a Heterogeneous Local Air-Defense System. M. L. Leibowitz and G. J. Lieberman. *Oper. Res.*, May-June, 1960, pp. 324–337. 11 refs. Discussion of the determination of the optimal combination of defensive missile batteries, and the deployment of that mix so as to obtain the best defense against the entire spectrum of enemy attack tactics, each defined in terms of speed, altitude, bomber cross section, and raid size. A general approach is outlined, the model is developed, and the solution obtained for the special case in which the measure of effectiveness is linear with respect to both raid size and the number of defense units.

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Special Issue: Polaris, FBM Program Starts Rolling. *Missiles & Rockets*, July 25, 1960, pp. 11–13, 18–34. *Partial Contents:* Integration Expedites Production, F. G. McGuire. Longer Range Promised Through Improved Motors. FBM Accuracy Starts with SINS, Ch. D. LaFond. "Pop-Up" Site Saves Millions in Polaris R&D. Bigger, Better Subs Are Coming. Assembling and Loading.

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L'Influence de Tangage sur la Vitesse Critique de Flottement des Engins. C. Béatrix. *La Recherche Aéronautique*, Jan.-Feb., 1960, pp. 55–59. In French. Study of the effect of pitch on the critical flutter velocities and frequencies of missiles, based on a system with two degrees of freedom. The results are applicable to the modification of pertinent parameters at the design stage.

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Atlas as a Space Booster. *The Aeroplane & Astronautics*, July 1, 1960, pp. 17–19. Presentation of the development history of the Atlas

missile and of the goals of current or planned space programs involving Atlas or Centaur, a Convair space vehicle derived from the Atlas.

Structural Effects and Particle Content of Interplanetary Space. L. Reiffel. *ARS J.*, July, 1960, pp. 654, 655. 14 refs. Presentation of calculations on structural damage by solar plasmas which show that solar helium is the dominant influence in sputtering, whereas solar hydrogen dominates radiation damage effects. Newly available laboratory data are used to calculate erosion rates in space.

Limitations of a Rocket Propulsion System with Variable Exhaust Velocity Taking Into Consideration Nuclear Data. Trutz Foelsche. *J. Astron. Sci.*, Summer, 1960, pp. 25–28. 12 refs. Analysis showing that, for nuclear physical reasons, an end velocity higher than $0.134c$ cannot be attained by a rocket using a propulsion system which maximizes the end velocity, at given energy content and end mass, by varying the exhaust velocity or by using propellants with variable combustion heat.

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Manometer Error Caused by Small Leaks in the Casing of a Satellite. S. A. Kuchay. (*Iskusstv. Sputniki Zemli*, No. 3, 1959, pp. 113–117.) *ARS J. Suppl.*, July, 1960, pp. 658–660. (Also in *U.S., NASA TT F-14*, Apr., 1960.) Translation. Study of manometer errors on the basis of assumptions concerning the source of leaks, the gaseous surroundings, and the laws pertaining to the scattering of molecules.

Magnetic Measurements in Space. Dolan Mansir. *Electronics*, Aug. 5, 1960, pp. 47–51. Discussion of the principles and design of proton precessional and optically pumped magnetometers.

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Automatic Test Equipment Checks Missile Systems. D. B. Dobson and L. L. Wolff. *Electronics*, July 15, 1960, pp. 74–78. Presentation of the design and operation of the Digital Evaluation Equipment.

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Simple Method for Approximating the Characteristics of Low Thrust Trajectories. P. D. Arthur, H. K. Karrenberg, and H. M. Stark. *ARS J.*, July, 1960, pp. 649–652.

Research Focuses on Re-Entry Problems. J. F. Judge. *Missiles & Rockets*, May 30, 1960, pp. 69–72. Discussion of the re-entry problem for various configurations and trajectories emphasizing the material requirements involved.

Normal Dispersion of a Re-Entry Body. R. A. Norling. *ARS J.*, July, 1960, pp. 652–654. Development of a solution for the normal dispersion or displacement of a re-entry body from its static path due to a small aerodynamic trim misalignment for the planar case. An expression is obtained which relates the normal dispersion as a variable function of altitude.

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System for Determination of the Parameter of the Motion of a Body in Space. G. O. Fridlender. (*AN SSSR Otd. Tekh. Nauk Izv. Energ. i Avtom.*, Nov.-Dec., 1959, pp. 108–117.) *ARS J. Suppl.*, July, 1960, pp. 685–690. Translation. Study showing that the application of geosystems (systems for vehicles moving at a relatively low speed along the surface of the earth) in interplanetary space involves difficulties due to the weightlessness of sensitive accelerometer elements and, therefore, the absence of correction which leads to periods of nonturbulence. The difficulty is overcome by the method of double integration of the discrepancy between the data furnished by the system, which are converted to correspond to the optical system oriented toward the sun or the planet, and the real position of the system.

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Low Thrust Correction of Orbital Orientation. L. Rider. *ARS J.*, July, 1960, pp. 647, 648. Analysis showing that the orientation parameters of inclination angle and nodal longitude can be varied by a low thrust device continuously applied perpendicularly to the orbit plane with sense of application reversed twice in every revolution.

Terminal Guidance System for Satellite Rendezvous. W. H. Clohessy and R. S. Wiltshire. (*IAS Natl. Summer Meeting, Los Angeles, June 16–19, 1959, Paper 59-93.*) *J. Aerospace Sci.*, Sept., 1960, pp. 653–658, 674. Discussion of the rendezvous phase of the process of building a space station or of assembling, in orbit, a big unmanned satellite out of smaller ones. The dynamics of the rendezvous are studied, the equations of motion of the rendezvous satellite in a relative coordinate system are derived and used to compute a final injection velocity which would effect collision after a time τ. The instrumentation necessary to bring about rendezvous is presented.

Component Development for Atlas Inertial System. *Auto. Control*, July, 1960, pp. 23–25. Presentation of the history of the program designed to develop airborne computers, gyros, accelerometers, and platforms. New miniaturization techniques involve the arrangement of the circuits in such a manner that all functions are of the time-shared type, which results in weight savings and increased reliability.

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Designing the Control System for a Space Reentry Vehicle. William Beauchemin. (*SAE Natl. Aero. Meeting, New York, Apr. 5–8, 1960, Preprint 171A.*) *SAE J.*, July, 1960, pp. 78–80. Abridged.

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Space Stations Require Radical Design, Structures. J. S. Butz, Jr. *Av. Week & Space Tech.*, Aug. 1, 1960, pp. 54, 55, 57–62 (ff.). Discussion of the construction approaches and materials for, and the environmental conditions to be met by, a 30,000-lb. third generation space vehicle, including also radiation incidence and hazards.

A Self-Navigating Space-Probe. *The Aeroplane & Astronautics*, July 8, 1960, pp. 52, 53. Discussion of a probe designed to intercept Mars in its orbit and to secure a photograph from fairly close range. A guidance system of sufficient accuracy to ensure the return of the photograph to earth is also described.

Agena Structure Makes Wide Use of Magnesium. Irwin Stambler. *Space/Aeronautics*, July, 1960, pp. 52–56. Survey of design features of the Agena satellite, including the nose cone, engine attachment, fairings, and engine starting.

Scout Variant to Have Dyna-Soar Role. Russell Hawkes. *Av. Week & Space Tech.*, July 11, 1960, pp. 54, 55, 59, 61, 63. Description of the configuration variations in the Scout missile, and discussion of the types of payloads and testing programs that are planned for the vehicle.

Some New Satellite Equations. R. A. Struble. *ARS J.*, July, 1960, p. 649. Derivation of completely general equations of motion of a satellite relative to the true orbital plane—i.e., the plane which at each instant contains the satellite and its velocity vector.

Minimization of Characteristic Velocity for Two-Impulse Orbital Transfer. H. Munick, R. McGill, and G. E. Taylor. (*ARS 14th Annual Meeting, Wash., Nov. 16–20, 1959.*) *ARS J.*, July, 1960, pp. 638, 639. Analysis concerning the problem of Lawden, that of optimum transfer from a point on an elliptical orbit to a circular orbit. More generally, the absolute minimum characteristic velocity path is given for transfer between two arbitrary terminals.

The Intersection of Coplanar, Confocal Conic Sections. G. S. Gedeon. *J. Astron. Sci.*, Summer, 1960, pp. 45, 46.

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Natural Flight

Biophysics of Bird Flight. August Raspet. *Science*, July 22, 1960, pp. 191–200. 22 refs. Discussion of the aerodynamics of a bird's wing, in particular, that of motionless-wing gliding flight. Investigation procedures are described, the possible influence of various wing features (feathers, toothed leading edge, alula) is noted, aerodynamics of aircraft and bird are compared, and various aspects of the soaring flight are briefly presented.

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Navigation

Electronic Aids

Special Issue: Aero-Electronics. *The Aeroplane & Astronautics*, July 15, 1960, pp. 69–84. *Partial Contents*: Air Traffic Control Plans in the United Kingdom, V. A. M. Hunt. The Practical Approach to A.T.C. Problems, E. W. Pike. Reflections on Navaid Requirements, S. M. B. Lane. Aids to Navigation and Control.

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Long Range Radio Navigation Extended for Advanced Vehicles. W. B. Leaf. *Space/Aeronautics*, July, 1960, pp. 118–124. Discussion of the design features and performance capability of the Loran B and C, the Lambda, the Omega, and the "Land" systems.

A Computation Method for Accurate Position Determination Using the Gee Navigation System. K. N. Dodd. *Gl. Brit., RAE TN M.S. 63*, Feb., 1960. 9 pp.

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Can We Solve Air Traffic Problems? *Am. Engr.*, July, 1960, pp. 19–23. Comparison between present, mostly manual, air traffic control procedures and the currently tested automatic system involving the Data Processing Central. An automatic aircraft landing system, designed to handle landings during bad weather, and the TRACE project are also discussed.

Controlling the Nation's Air Traffic. *Librascope Tech. Rev.*, Spring, 1960, pp. 6, 7, 10–12. Discussion of the present and the planned equipment and procedures in the processing and display of air traffic control data. The functions, characteristics, and capabilities of the Librascope-developed data processor, which will be integrated with the data processing central, are studied; and the functions and reliability of the total system are considered.

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Nuclear Rocket Propulsion. *The Aeroplane & Astronautics*, June 24, 1960, pp. 773, 774. Discussion covering the achievements of the experimental program carried out by the Atomic Energy Commission to develop solid-core nuclear rocket engines, including special arrangements for the handling of the reactor during assembly and test to reduce contamination risks and to protect test personnel, as well as the program objectives.

Rankine Cycle Selected for Snap 2. G. M. Anderson. (*SAE Natl. Aero. Meeting, New York, Apr. 5–8, 1960, Preprint 154B.*) *SAE J.*, July, 1960, pp. 48–51. Abridged.

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The Behavior of Fuels and Lubricants in Dynamic Test Equipment Operating in the Presence of Gamma Radiation. *USAF WADC TR 58-264, Pt. II*, Mar. 31, 1959. 167 pp. 12 refs.

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Polarization Capacitance Determinations of Surface Roughness. M. K. Testerman. *USAF WADD TR 60-97*, Apr., 1960. 32 pp. 24 refs.

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Elastic and Inelastic Scattering of 4.1 Mev Neutrons from Ca, Mo, Sb, Ba, and Hg. L. D. Vincent, I. L. Morgan, and J. T. Prud'homme. *USAF WADD TR 60-217*, Apr., 1960. 56 pp. 40 refs.

Superconductive Properties of Vacuum Deposited Indium Films. Appendix A—**Techniques for Determining Thickness and Its Effect on Film Resistivity.** Appendix B—**Characteristics of Indium Films.** F. W. Schmidlin, E. C. Crittenden, Jr., A. J. Learn, and J. N. Cooper. *Space Tech. Lab. PRL 9-18*, 1960. 66 pp. ONR-supported research.

An Experimental Determination of the Absolute Oscillator Strengths of the Lines of Two N II Supermultiplets. Frithjof Mastrup. *U.S., NASA TT F-38*, May, 1960. 19 pp. 15 refs. Translation. OTS, $0.50. Presentation of the results of measurements made on some spectral lines of nitrogen at temperature of 20,000°K. A description of the apparatus for producing this temperature, a wall stabilized arc, is included.

General Research in Flight Sciences—Fluid Mechanics. V—Studies of Sputtering by Beam Techniques. R. P. Stein and F. Hurlbut. *Lockheed Aircraft Missiles & Space Div., vol. I, Pt. II, TR LMSD-288139*, Jan., 1959–Jan., 1960. 20 pp. USAF-Navy-supported review of low-energy sputtering of metallic surfaces. An experiment designed to provide information on the detailed mechanism of the sputtering process and the experimental apparatus for this study are described. The initial results and their interpretation are presented.

Use of Radioactive Iodine Vapor for Determining Surface Roughness. M. K. Testerman. *USAF WADC TR 59-659*, Dec., 1959. 42 pp. 25 refs.

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The Origin of the Solar System. W. H. McCrea. *Royal Soc. (London) Proc., Ser. A*, June 21, 1960, pp. 245–266. 11 refs. Presentation of a theory attempting to relate the origin of the solar system to the general problem of star formation.

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Electronics Probes Nature. II—Our Atmosphere. W. E. Bushor and M. F. Wolff. *Electronics*, July 29, 1960, pp. 63–66. Discussion of meteorological satellites, sounding rockets, and weather radars, and their application to the investigation of the atmosphere. The use of ozone measurements in these investigations is also noted.

Some Results of the Measurement of the Spectrum Mass of Positive Ions by the 3rd Artificial Earth Satellite. V. G. Istomin. *U.S., NASA TT F-7*, Apr., 1960. 19 pp. OTS, $0.50. Translation. Measurement of positive ions with mass values of 32, 30, 38, 18, 16, and 14 which are identified as single charged ions of molecular oxygen, nitrogen oxide, molecular nitrogen, atomic oxygen, and atomic nitrogen, respectively. The data obtained ranged from altitudes of 225 to 980 km. and latitudinal intervals of 27° to 65° north latitude.

Determination of Atmospheric Density at a Height of 430 km by Means of the Diffusion of Sodium Vapors. I. S. Shklovskii and V. G. Kurt. (*Iskusstv. Sputniki Zemli*, No. 3, 1959, pp. 66–76.) *ARS J. Suppl.*, July, 1960, pp. 662–667. 16 refs. (Also in *U.S., NASA TT F-15*, Apr., 1960.) Translation. Presentation of a method having application in the lower limit of 200 km. and between 500 and 600 km. in the upper limiting region.

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The Measurement of Winds Between 100,000 and 300,000 ft by Use of Chaff Rockets. L. B. Smith. *J. Meteorology*, June, 1960, pp. 296–310. 26 refs. Presentation of a height profile of the measured winds, obtained from radar tracking of chaff expelled from rockets. The two-stage rocket-delivery system is also described.

Number of Extensive Atmospheric Showers of Cosmic Rays Near Sea Level. S. I. Mishnev and S. I. Nikol'skii. (*Zhurnal Teoret. i Exper. Fiz.*, Jan., 1960, pp. 257, 258.) *Sov. Phys. - JETP*, July, 1960, pp. 186, 187. Translation. Presentation of a more sensitive method for the registration and investigation of individual atmospheric showers, including results obtained with this procedure.

Ultra-High-Energy Extensive Air Showers. A. T. Abrosimov, G. A. Bazilevskaya, V. I. Solov'eva, and G. B. Khristiansen. (*Zhurnal Teoret. i Exper. Fiz.*, Jan., 1960, pp. 100–107.) *Sov. Phys. - JETP*, July, 1960, pp. 74–79. 17 refs. Translation. Investigation of extensive air showers having from 5×10^6 to 10^8 particles. Data are presented on the absolute shower intensity, the value spectrum exponent, and on the lateral distributions of the electron-photon component and of the μ mesons of these showers.

Comparison of Different Coordinate Conditions in Einstein's Gravitation Theory. V. A. Fock. (*Zhurnal Teoret. i Exper. Fiz.*, Jan., 1960, pp. 108–115.) *Sov. Phys. - JETP*, July, 1960, pp. 80–84. Translation.

Optics

Considerations Regarding the Possible Use of Some Optical Elements. N. Bárány. *Periodica Polytech., Elec. Eng. Ser.*, No. 3, 1959, pp. 183–196. Review of adjusting devices adapted for use in optomechanical instruments, including also certain mechanical constructions which are used in military instruments but which are applicable for general use.

Criteria for the Performance of Infrared Systems. R. W. Powell. *OSA J.*, July, 1960, pp. 660–667. Presentation of a new method of performance evaluation to supplement the one currently used. The determination of the responsivity curve is discussed. The relative response of the system to blackbody radiation between 273°K. (0°C.) and 6,000°K. is computed from the response curve, thereby more completely defining the system's performance against various targets and backgrounds.

Power Plants

Basic Energy Conversion in Space Vehicles. J. H. Fisher and Ch. W. Stephens. *Electro-Optical Systems, Paper*, 1959. 17 pp. Discussion of energy sources, energy converters, and energy rejectors as they influence or are influenced by the Carnot cycle and the energy balance on a vehicle isolated in space.

Electric Space Propulsion. J. C. Evvard. (*AIEE Fall Gen. Meeting, Chicago, Oct. 11–16, 1959.*) *Elec. Eng.*, July, 1960, pp. 555–563. 35 refs. Abridged. Discussion of the general characteristics of electric propulsion systems for space vehicles, the energy sources and conversion efficiencies available, projected power-plant weights, and some of the various schemes for generating the ion and plasma jets. Also included are results of experimental units and their feasible range of application.

Pierce Gun Design for an Accelerate-Decelerate Ionic Thrust Device. M. J. Raether and R. N. Seitz. (*ARS Semi-Annual Meeting, San Diego, June 8–11, 1959.*) *ARS J.*, July, 1960, pp. 640–642.

Zero Gravity Mercury Condensing Research. J. G. Reitz. *Aerospace Engrg.*, Sept., 1960, pp. 18–23, 46. Discussion of zero *g* tests which were part of a condenser research program conducted to design trouble-free liquid metal space condensers. Conclusions from these tests are applicable to three areas of space power system technology—feasibility demonstration, ground test validation, and problem identification.

Jet & Turbine

Presentation of a Blade-Design Method for Axial-Flow Turbines, Including Design and Test Results of a Typical Axial-Flow Stage. F. Baumgartner and R. Amsler. (*ASME Gas Turbine Power Conf., Cincinnati, Mar. 8–11, 1959, Paper 59-GTP-4.*) *ASME Trans., Ser. A - EP*, Jan., 1960, pp. 19–26. Discussion of a method, based on the concept of aerodynamic blade loading, for determining the shape of stationary nozzle blades and rotor blades for an axial-flow-type turbine. By applying the method, airfoil shapes are obtained which satisfy the momentum requirements regardless of what blade-load distribution is assumed, as long as the mean blade load remains constant. A specific application of the design method is described and test data are presented which show that good agreement between design goal and test results was achieved.

O Primenimosti Kriteriia L'enara k Vyiavleniiu Avtokolebanii Lopatok Turbomashin. N. S. Lobikov. *MVO SSSR VUZ Izv. Av. Tekh.*, No. 2, 1960, pp. 129–137. In Russian. Tentative determination of self-excited bending oscillations of turbine blades on the basis of the beam theory and using the steady aerodynamic flow hypothesis.

Development of a Three-Stage Liquid-Cooled Gas Turbine. Summer Alpert, R. E. Grey, and W. O. Flaschar. (*ASME Gas Turbine Power Conf., Cincinnati, Mar. 8–11, 1959, Paper 59-GTP-1.*) *ASME Trans., Ser. A - EP*, Jan., 1960, pp. 1–9. Discussion of the design and test work conducted to develop a three-stage, liquid-cooled gas turbine which would operate at 1,750°F. inlet temperature with nonstrategic, low-alloy components. The performance characteristics are included.

Fan Burner Dominates Supersonic Designs. J. S. Butz. *Av. Week & Space Tech.*, July 11, 1960, pp. 96, 97, 101–103, 105. Discussion of a

new class of high-performance turbojet engines, including requirements, military potential, design, and problem areas.

Reciprocating

Issledovanie Protsessov Iznashivaniia v Detaliakh Aviatsionnykh Dvigatelei, Pokrytykh Elektroliticheskim Khromom. D. S. Plishko. *MVO SSSR VUZ Izv. Av. Tekh.*, No. 2, 1960, pp. 157–167. In Russian. Description of tests made to study the wear of aircraft power-plant components coated with electrolytic chromium.

Rocket

"Catastrophic" Changes in Burning Rate of Solid Propellants During Combustion Instability. J. E. Crump and E. W. Price. *ARS J.*, July, 1960, pp. 705–707. Investigation that reveals a "catastrophic" change in burning rate which is correlated with the occurrence of a hormonic relationship between a longitudinal acoustic mode and a tangential acoustic mode of the propellant chamber.

Propellant Vaporization as a Design Criterion for Rocket-Engine Combustion Chambers. Appendix—**Physical Properties.** R. J. Priem and M. F. Heidmann. *U.S., NASA TR R-67*, 1960. 127 pp. 35 refs. Presentation of calculated vaporization rates and histories for sprays of ammonia, hydrazine, oxygen, and fluorine. The results are correlated with an effective chamber length for ease in using them for design purposes.

Nomad Vehicle Features Exotic Fuel; Promises Super Second-Stage Performance—First Report. Walt Keeshen, Jr. *Western Av.*, July, 1960, pp. 18–20, 26, 28. Presentation of a new concept of rocket nozzle contour which, because of the absence of thrust loss associated with overexpansion, is efficient over a wide range of operating pressure ratios. For the same thrust as that of a conventional bell nozzle, the new type is only half as long. Test results concerning the feasibility of an annular combustion chamber and the operation of the new rocket nozzle are discussed.

Production

Missouri Town Makes Rocket Engines. Jay Holmes. *Missiles & Rockets*, Aug. 1, 1960, pp. 28–30. Description of the Rocketdyne Neosho facilities producing the liquid-propellant rocket for the Jupiter, Thor, and Atlas, including the engine capabilities, design improvements, aluminum alloy used, fabrication steps, and production organization.

Metalworking

High Energy Rate Forming Processes—Their Present and Future. Donald Peckner. *Materials in Des. Eng.*, July, 1960, pp. 89–96. Discussion of explosive forming, expanding gas systems, Dynapak process, and hydrospark forming methods, covering the materials, applications, and cost considerations.

Large Ring Parts. *Aircraft Prod.*, July, 1960, pp. 256–261. Presentation of the design of a Floturning machine capable of producing long, seamless tubular parts suitable for rocket or missile parts or other applications.

Some Problems in Flanging and Beading Membranes. B. V. Grigoryev. *U.S., NASA TT F-32*, June, 1960. 13 pp. Translation. OTS, $0.50. Discussion of hydraulic forming of thin metal diaphragm material. The presented method gives considerably more stable properties and less residual deformations, elastic fatigue, and hysteresis. Consideration is given to the problem of the pressure necessary for forming the diaphragm and utilizing this pressure to reinforce the clamping pressure of the blank against the rim.

Le Matriçage de Précision. M. Enfer. *Tech. & Sci. Aéronautiques*, Nov.-Dec., 1959, pp. 365–368. In French. Description of a precision die-stamping technique, and evaluation of its advantages in the fabrication of blades for gas turbine compressors.

Heat Treaters' Dilemma—Intolerant Tolerances. H. C. Knerr. *Missiles & Rockets*, Aug. 1, 1960, pp. 36–38. Presentation of actual examples of specifications illustrating the extreme, and possibly unnecessary, requirements. A closer cooperation between designer and metallurgist is called for.

Electro-Erosion: Higher Powers with Rotary Generators. Christopher Dawson. *Space/Aeronautics*, July, 1960, pp. 79, 80, 82–86 (ff.). Discussion of the method of erosion by electric spark or arc, including improved procedures, and of European equipment developed for this precision metalworking process.

Machining Nimonic. II. *Aircraft Prod.*, July, 1960, pp. 275–279. Discussion of grinding, milling, drilling, and broaching techniques for the Nimonic high-nickel alloys.

Machining Thin Discs. I—Development of Production Techniques at Rolls-Royce Ltd: Design of a Special Duplex-Slide Lathe. H. J. Pearson. *Aircraft Prod.*, July, 1960, pp. 244–254.

Issledovanie Protsessa Gibki-Prokatki Profil'nykh Detalei na Asimmetrichnykh Rolikovykh Profilegibochnykh Stankakh. Chzhan Tsziun'. *MVO SSSR VUZ Izv. Av. Tekh.*, No. 2, 1960, pp. 168–176. In Russian. Evaluation of the bending-rolling process for profiles having one cross-sectional axis of symmetry and subjected to bending in the plane of this axis.

O Kinetike Okislitel'no-Vosstanovitel'nykh Reaktsii pri Svarke. A. A. Erokhin. *AN SSSR Otd. Tekh. Nauk Izv. Metall. i Toplivo*, Jan.-Feb., 1960, pp. 36–43. 11 refs. In Russian. Tentative definition of the kinetic factor in the process of metal oxidation during welding.

Brazed Joints for 1000 F and Above. J. C. Reeves. *Prod. Eng.*, Aug. 1, 1960, pp. 40–45. Presentation of the principles, applications, materials, and method of a high-temperature brazing procedure joining efficiently stainless steels, alloy steels, and the superalloys.

Nonmetalworking

Möglichkeiten des Metallklebens. Alexander Matting. (*WGL Jahrestagung, Hamburg, Oct. 14, 1959.*) *ZFW*, June, 1960, pp. 153–160. 14 refs. In German. Discussion of metal-gluing techniques in aircraft construction, emphasizing the synthetic resin, cold-hardening glues.

Propellers

Vortex Theory of an Airscrew in Consideration of Contraction or Expansion of Slipstream and Variation of Pitch of Vortex Sheets in It. Matsunosuke Iwasaki. *Kyushu U. Rep. Res. Inst. Appl. Mech.*, No. 27, 1959, pp. 159–232. 10 refs.

Reference Works

Bibliography on Plasma Physics and Magnetohydrodynamics and Their Applications to Controlled Thermonuclear Reactions. Compiled by J. D. Ramer, C. K. Lewe, and Maurice Barkley. *U. Md. Eng. & Phys. Sci. Lab.*, 1960. 105 pp. 1,707 refs. Survey of the international literature of the period from 1937 to 1959 covering the subject of magnetohydrodynamics. Included are an alphabetically arranged list of journals referred to in the bibliography and a numerical index to atomic energy reports.

Research, Research Facilities

Realisation of a Molecular Gun or Cosmic Wind Tunnel. F. M. Devienne. *Lab. Méditerranéen de Rech. Thermodynamiques TN (EOARDC TN 59-1292)*, Oct., 1959. 57 pp. 21 refs. Description of a molecular gun to reproduce the conditions of a solid body moving at a cosmic speed in a rarefied gas. The apparatus is based on the exchange momentum between two crossed beams, one of these being a molecular beam corresponding to an ordinary temperature, and the other, an ion beam in which the ions are accelerated by voltages included between a few volts and a few hundred volts.

Preliminary Research on a Molecular Beam for the 1-10 ev Range. Appendix I—**Relationship Between Collision Integrals and Experimental Measurements.** G. T. Skinner and C. E. Treanor. Appendix II—**Dynamical Feynman's Theorem.** E. H. Kerner. *Cornell Aero. Lab. Rep. AD-1118-A-9 (AFOSR TN 59-1086)*, Dec., 1959. 61 pp. 23 refs. Discussion of the design and construction of a molecular-beam apparatus for the production of atomic and molecular beams. A shock tube is used as the source of high-temperature, high-pressure gas, and a hypersonic expansion is used to obtain a high-energy, nearly mono-energetic beam. The use of a two-center potential for the treatment of atom-molecule collisions is discussed.

Simulation of Environmental Conditions in Near Space. J. C. Simons, Jr. *ARS 14th Annual Meeting & Astron. Exp., Wash., Nov. 16–20, 1959, Paper.* 18 pp. 16 refs. Discussion of the technological and economic feasibility of simulating the various factors of the space environment.

A Review of the Development of High Enthalpy Aerodynamic Test Facilities. B. D. Henshall. *Appl. Mech. Rev.*, June, 1960, pp. 387–390. 44 refs. Discussion of the various types of short-duration wind tunnels developed in the past decade and details of the operation of each type of facility. Performance studies on gun tunnels and hotshot tunnels are presented; it is concluded that the large, expensive, arc-heated continuous wind tunnel is the ultimate structural and aerodynamic installation.

Flight Testing

Endurance and Reliability Testing of the CJ805. R. J. Scoles. *Soc. Exp. Test Pilots Quart. Rev.*, Spring, 1960, pp. 13–17. Discussion of the flight test program for the CJ805 using a modified Douglas B-66 bomber.

Wind Tunnels

A Comparison of Test Results from Three Transonic Tunnels for Two Sets of Geometrically Similar Models. Appendix—**Values of the Blockage and Upwash Constraint Corrections for Slotted Tunnels.** L. C. Squire. *Gt. Brit., RAE TN Aero. 2679*, Mar., 1960. 53 pp. 17 refs. Presentation of test results to assess wind tunnel constraint effects on the models in the speed range from Mach number 0.80 to 1.25.

The Centre-Line Mach-Number Distributions and Auxiliary-Suction Requirements for the A.R.A. 9-ft x 8-ft Transonic Wind Tunnel. A. B. Haines and J. C. M. Jones. *Gt. Brit., ARC R&M 3140* (Apr., 1958) 1960. 51 pp. BIS, New York, $3.15. Presentation of the centerline Mach number distributions obtained during calibration in the transonic wind tunnel. It is shown how these are affected by changes in suction quantity, wall geometry, and nozzle setting and how, particularly at low supersonic Mach numbers, they are improved by modifications to the distribution of wall porosity along the length of the working section.

Recent Developments Connected with the Hypersonic Facility of the Polytechnic Institute of Brooklyn. I—Tests of the Compression Heater. II—Aspects of the Design, Construction and Installation of a Multiple-Outlet Collector for the Convection Heater. S. R. Panunzio. *USAF WADD TR 60-94*, Oct., 1959. 23 pp. 11 refs.

Rotating Wing Aircraft, Helicopters

Sélection des Paramètres Aérodynamiques pour l'Étude des Hélicoptères. Igor Alexis Sikorsky. (*4th Internatl. Aero. Congr. on Rotary Wings & Vertical Flight, Paris, June 15–19, 1959.*) *Tech. & Sci. Aéronautiques*, Sept.-Oct., 1959, pp. 258–272. 61 refs. In French. Discussion of the selection of aerodynamic parameters for the study of helicopters. The survey covers: (a) history of helicopter development; (b) aerodynamic considerations for hovering and vertical flight; (c) aerodynamic considerations for forward translational flight; and (d) general considerations covering stall and compressibility effects, as well as the role of weight, dimensions, and economics.

Raschet Svobodnykh Kolebanii Vrashchaiushcheisia Lopasti Vertoleta s Pomoshch'iu Matrits. M. B. Vakhitov. *MVO SSSR VUZ Izv. Av. Tekh.*, No. 2, 1960, pp. 31–41. 12 refs. In Russian. Derivation of matrix equations for the free bending oscillations in the flapping plane of a rotating helicopter blade, oscillations of a non-rotating blade, and the parametric oscillations by generalizing the matrix equation of the static blade bending.

Safety

Observations on Safety. Jerome Lederer. *Radio Tech. Comm. for Aeronautics Meeting, Atlantic City, Oct. 15, 1959, Paper.* 14 pp. Discussion of conventional subsonic airplanes, VTOL/STOL aircraft, proximity vehicles, supersonic airliners, and space vehicles as factors in the problem of safety. The specific problems of collision prevention, landing, and general aviation are discussed.

The Effects of Cabin Atmospheres on Combustion of Some Flammable Aircraft Materials. H. A. Klein. *USAF WADC TR 59-456*, Apr., 1960. 26 pp.

Structures

Stresses in a Slab Having a Spherical Cavity Under Circular Bending. Chih-Bing Ling and Chen-Peng Tsai. (*ASME Annual Meeting, Atlantic City, Nov. 29–Dec. 4, 1959, Paper 59-A-64.*) *ASME Trans., Ser. E - AM*, June, 1960, pp. 278–282. Presentation of an analysis of the effect of a spherical cavity in a solid of revolution when the solid is acted on by a given stress system symmetrical to the axis of revolution. The stresses in the slab are investigated when the slab is under circular bending around its edge. The solution of the problem is illustrated by numerical examples for two radii of the cavity. In particular, the maximum stresses in the slab are computed to show the effect of the cavity on the stresses in the slab.

Strain-Hardening Solutions to Axisymmetric Disks and Tubes. Nicholas Perrone. (*ASME Annual Meeting, Atlantic City, Nov. 29–Dec. 4, 1959, Paper 59-A-29.*) *ASME Trans., Ser. E - AM*, Mar., 1960, pp. 45–53. 12 refs. Navy-sponsored presentation of solutions for annular discs and tubes made of a linearly strain-hardened material, loaded by a uniform tensile load on the outer boundary. In addition, a second solution for tubes which accounts for finite deformation is determined. Some numerical comparisons are made with existing isotropic hardening solutions.

Bars & Rods

The Second Approximation for Buckling Loads of Tapered Struts. M. M. Abbassi. *ASME Trans., Ser. E - AM*, Mar., 1960, pp. 211, 212. Extension of a previously developed method to obtain the second approximation for a certain differential equation. This solution is then applied to determine more accurately the critical buckling loads for tapered struts.

Beams & Columns

Dominance of Shear Stresses in Early Stages of Impulsive Motion of Beams. H. H. Bleich and R. Shaw. (*ASME Annual Meeting, Atlantic City, Nov. 29–Dec. 4, 1959, Paper 59–A-60.*) *ASME Trans., Ser. E - AM*, Mar., 1960, pp. 132–138. Navy-sponsored investigation of the magnitude of bending stresses and shear stresses in beams under the action of impulsive forces which are determined from the differential equations for the Timoshenko beam. It is found that in the early stages, soon after the initiation of the motion, the shear stresses are of much larger magnitude than the bending stresses.

On the Effect of Shear on Plastic Deformation of Beams Under Transverse Impact Loading. B. Karunes and E. T. Onat. (*ASME West Coast Conf., Stanford, Sept. 9–11, 1959, Paper 59–APMW-7.*) *ASME Trans., Ser. E - AM*, Mar., 1960, pp. 107–110. 11 refs. Navy-supported presentation of an analysis of the impact problem for a rigid-plastic beam, formulated by using an interaction curve relating shearing force and bending moment for fully plastic action, and allowing for shear and rotary inertia effects. Using a simplified interaction diagram, the problem of joint-impact loading is solved for a special case.

Distribution of Shear Stress in a Box Beam. B. A. Walker. *The Engr.*, June 24, 1960, pp. 1067–1069. Analysis of the bending shear force distribution in a symmetrical box beam with three webs of equal thickness. It is shown that the shear stress in the center web is always greater than in the side webs and that this difference is of the order of 20 to 30 per cent for most box beams found in practice. The method given can be applied to other cases of symmetrical box beams.

Upper and Lower Bounds for the Center of Flexure. L. E. Payne. *J. Res., Sect. B - MMP*, Apr.–June, 1960, pp. 105–111. 11 refs. Presentation of upper and lower bounds for the coordinates of the center of flexure of an isotropic elastic beam.

On the Elastic Bending of Columns Due to Dynamic Axial Forces Including Effects of Axial Inertia. Eugene Sevin. (*ASME Annual Meeting, Atlantic City, Nov. 29–Dec. 4, 1959, Paper 59–A-25.*) *ASME Trans., Ser. E - AM*, Mar., 1960, pp. 125–131. 12 refs. Investigation of the influence of axial inertia upon the elastic bending motion of initially slightly curved columns acted on by time-dependent axial forces. Numerical solutions are obtained for a problem similar to the one studied by Hoff but in which axial-inertia effects were neglected.

Cylinders & Shells

On a Certain Dynamic Problem of Elasticity for a Circular Cylinder. W. Derski. *Acad. Pol. Sci. Bul., Tech. Sci. Ser.*, No. 3, 1960, pp. 135–138. Analysis of the dynamic effects observed when an infinite circular cylinder is subjected to a sudden action of temperature on its lateral surface.

Edge Influence Coefficients for Toroidal Shells of Positive Gaussian Curvature. G. D. Galletly. (*ASME Petroleum-Mech. Eng. Conf., Houston, Sept. 20–23, 1959, Paper 59–Pet-2.*) *ASME Trans., Ser. B - EI*, Feb., 1960, pp. 60–68. 15 refs. Investigation determining accurately the edge influence coefficients for constant-thickness toroidal shells subjected to uniform pressure and edge bending loads.

Edge Influence Coefficients for Toroidal Shells of Negative Gaussian Curvature. G. D. Galletly. (*ASME Petroleum-Mech. Eng. Conf., Houston, Sept. 20–23, 1959, Paper 59–Pet-3.*) *ASME Trans., Ser. B - EI*, Feb., 1960, pp. 69, 70.

On the Optimum Design of Shells. R. T. Shield. (*ASME Annual Meeting, Atlantic City, Nov. 29–Dec. 4, 1959, Paper 59–A-47.*) *ASME Trans., Ser. E - AM*, June, 1960, pp. 316–322. Army-sponsored presentation of a method developed for obtaining the design of an elastic, perfectly plastic shell or structure which will support prescribed loads and which is the optimum design for a given criterion. The action of body forces is included in the analysis. Some problems in the minimum volume design of a circular cylindrical sandwich shell are solved to illustrate the method.

On Stress-Strain Relations and Strain-Energy Expressions in the Theory of Thin Elastic Shells. J. K. Knowles and Eric Reissner. (*ASME West Coast Conf., Stanford, Sept. 9–11, 1959, Paper 59–APMW-13.*) *ASME Trans., Ser. E - AM*, Mar., 1960, pp. 104–106. Navy-sponsored presentation of an inversion of the stress-strain relations of Flügge and Byrne for thin elastic shells to express strain quantities, and therewith the strain energy, in terms of stress resultants and couples. The stress-strain relations and the strain-energy expression are shown to be simply related to corresponding results of Trefftz. The strain-energy formula of Trefftz is generalized to arbitrary orthogonal middle surface coordinates.

The Elastic-Plastic Response of Thin Spherical Shells to Internal Blast Loading. W. E. Baker. (*ASME Annual Meeting, Atlantic City, Nov. 29–Dec. 4, 1959, Paper 59–A-95.*) *ASME Trans., Ser. E-AM*, Mar., 1960, pp. 139–144. Presentation of a theory for the elastic-plastic response of a thin spherical shell to spherically symmetric internal transient pressure loading. Analytic solutions are obtained to the linear, small-deflection equations of motion for shell materials which exhibit various degrees of strain hardening. Numerical solutions obtained by digital computer are also presented for the equations for large deflections obtained by accounting for shell thinning and increase in radius during deformation. The theory is compared with experiment and is shown to be in good agreement.

Yield Conditions for Rotationally Symmetric Shells Under Axisymmetric Loading. P. G. Hodge, Jr. (*ASME Annual Meeting, Atlantic City, Nov. 29–Dec. 4, 1959, Paper 59–A-129.*) *ASME Trans., Ser. E - AM*, June, 1960, pp. 323–331. 12 refs. Navy-sponsored presentation of the exact yield surface according to the Tresca yield condition as compared with various approximations. A new approximation is suggested which combines the advantages of mathematical simplicity with reasonable accuracy. The theory is illustrated with reference to a spherical cap under uniform pressure.

Response of Shallow Viscoelastic Spherical Shells to Time-Dependent Axisymmetric Loads. P. M. Naghdi and W. C. Orthwein. *Quart. Appl. Math.*, July, 1960, pp. 107–121. 18 refs. USAF-sponsored presentation of solutions employing the differential equations governing the transverse motion of shallow elastic shells, obtained with the joint use of the Laplace and Hankel transforms.

Raschet Krugovykh Ortotropnykh Konicheskikh Obolochek. R. A. Malakhovskii. *MVO SSSR VUZ Izv. Av. Tekh.*, No. 2, 1960, pp. 61–68. In Russian. Study of the state of stress in thin, elastic, stringer reinforced conical shells. The approximate solution is applicable to aircraft structures having small conicity angle and not too small relative thickness. Taking into account the Duhamel-Neumann hypothesis, the method can be extended to the case of thermally stressed shells in a three-dimensional temperature field.

K Teorii Uprugo-Plasticheskoi Ustoichivosti Bimetallicheskikh Obolochek. A. V. Sachenkov. *MVO SSSR VUZ Izv. Av. Tekh.*, No. 2, 1960, pp. 69–79. In Russian. Presentation of solutions for the elasto-plastic stability of bimetallic shells. Includes determination of conditions reducing the calculation to that of monolayer anisotropic elastic shells.

K Teorii Anizotropnykh Obolochek. B. G. Gazizov. *MVO SSSR VUZ Izv. Av. Tekh.*, No. 2, 1960, pp. 42–49. In Russian. Derivation of basic equations in the theory of bending and stability of curved anisotropic shells with transversal isotropy. The results of the calculation are generalized to cover the case of two-layer anisotropic shells with transversal isotropy, and the possibility of a generalization for the case of multilayer shells is indicated.

Asymptotic Integration of the Differential Equation for a Special Case of Symmetrically Loaded Toroidal Shells. Osmund Jenssen. *J. Math. & Phys.*, Apr., 1960, pp. 1–17. Analysis considering toroidal shells where the meridian circles have the axis of rotation as a common tangent at the origin. A method is presented to obtain the particular integral of equations similar to those used by Clark in his treatment of toroidal shells.

Elasticity & Plasticity

On the Theory of Ideally Plastic Anisotropy. D. D. Ivlev. (*Prikl. Mat. i Mekh.*, Nov.-Dec., 1959, pp. 1107–1114.) *PMM—Appl. Math. & Mech.*, No. 6, 1959, pp. 1582–1592. Translation. Study of the behavior of an ideally rigid plastic body, considered under a generalized Tresca plasticity condition.

On the Propagation of Elasto-Plastic Waves for Combined Stresses. N. Cristescu. (*Prikl. Mat. i Mekh.*, Nov.-Dec., 1959, pp. 1124–1128.) *PMM—Appl. Math. & Mech.*, No. 6, 1959, pp. 1605–1612. Translation. Extension of the problem on the basis of the equations established by Rakhmatulin to include another possible case of propagation which may occur for certain materials. This occurs when the combined dynamic stress is transmitted in a plastic body only by combined waves that propagate faster than the usual plastic waves.

Plane Strain Problems for a Perfectly Elastic Material of Harmonic Type. Fritz John. *Commun. on Pure & Appl. Math.*, May, 1960, pp. 239–296. 16 refs. USAF-supported derivation of the stress-strain for finite strain relations from the expression for the strain energy density by means of the principle of virtual work. The behavior of the material under prescribed forces or displacements is described in terms of differential equations and boundary conditions.

A Method of Solution for the Elastic Quarter-Plane. M. Hetényi. (*ASME Annual Meeting, Atlantic City, Nov. 29–Dec. 4, 1959, Paper 59–A-92.*) *ASME Trans., Ser. E - AM*, June, 1960, pp. 289–296. Analysis showing that for given loads on the elastic quarter-plane, the prescribed boundary conditions can be fulfilled by repeated superposition of known solutions for the elastic half-plane. The solution is exact, since the sequence may be continued to obtain any required accuracy. Solutions are derived in this manner for three types of boundary loads: (a) concentrated normal force, (b) concentrated tangential force, and (c) partially distributed uniform loading.

Plastic-Wave Propagation Effects in Transverse Impact of Membranes. B. Karunes and E. T. Onat. (*ASME Annual Meeting, Atlantic City, Nov. 29–Dec. 4, 1959, Paper 59–A-128.*) *ASME Trans., Ser. E - AM*, Mar., 1960, pp. 172–176. Navy-supported investigation of the plane motion of a rigid strain hardening membrane attached to two parallel fixed supports and subjected to a uniformly distributed transverse impulse. Particular emphasis is given to the variation of thickness in the final deflected shape.

Fatigue

Essais Comparatifs de Fatigue sur Eléments de Construction Aéronautique Soudés par Points ou Rivés. R. Cazaud. *Tech. & Sci. Aéronautiques*, Nov.-Dec., 1959, pp. 389–391. In French. Description of comparative tests on spot welded or riveted structural elements corresponding to typical assemblies used in the construction of Caravelle.

Plates

Bending of an Unbounded Plate Supported by an Elastic Half-Space with a Modulus of Elasticity Varying with Depth. G. Ia. Popov. (*Prikl. Mat. i Mekh.*, Nov.-Dec., 1959, pp. 1095–1100.) *PMM—Appl. Math. & Mech.*, No. 6, 1959, pp. 1566–1573. Translation.

Bending of an Isotropic Triangular Plate, Two of Whose Edges Are Simply Supported and the Third Clamped. B. D. Aggarwala. *ASME Trans., Ser. E - AM*, June, 1960, pp. 357, 358. Presentation of a relation between stress concentration and boundary displacement which applies for openings in the form of circles and ellipses, loaded parallel to a semiaxis.

Effect of Shear Deformations on the Bending of Rectangular Plates. V. L. Salerno and M. A. Goldberg. (*ASME Annual Meeting, Atlantic City, Nov. 29–Dec. 4, 1959, Paper 59–A-66.*) *ASME Trans., Ser. E - AM*, Mar., 1960, pp. 54–58. Presentation of a reduction of Reissner's three partial differential equations to a fourth-order partial differential equation resembling that of the classical plate theory and to a second-order differential equation for determining a stress function. The general solution for the two partial differential equations is then applied to a simply supported plate with a constant load p and to a plate with two opposite edges simply supported, and the other two edges free. Numerical calculations are presented for the simply supported plate and the results compared with those of classical theory.

Axisymmetric Bending Stresses in Solid Circular Plates with Thermal Gradients. Marvin Forray and Malcolm Newman. *J. Aerospace Sci.*, Sept., 1960, pp. 717, 718. USAF-supported presentation of a direct solution to the problem by solving the partial differential equation for the deflection. Curves and formulas useful to the practicing engineer are included.

Cylindrically Orthotropic Circular Plates with Large Deflections. Jerzy Nowinski. *ZAMP*, May 25, 1960, pp. 218–227. 10 refs. Army-sponsored analysis of membrane and bending stresses, using for comparison the perturbation method of Poincaré and a modification of the Galerkin method based on the energy concept. A numerical example is given for the case of uniform loading of a plate, the Poisson number $\nu_\phi = 1/4$, and the relation $\nu_\phi : \nu_2 = 4$.

Influence of an External Load on an Elliptical Disc. F. Szelągowski. *Acad. Pol. Sci. Bul., Tech. Sci. Ser.*, No. 3, 1960, pp. 123–128. Discussion of the problem of tension in an elliptical isotropic disc under the influence of a given external load. The problem is reduced to the determination of the stresses occurring at an arbitrary point in the disc and the displacements.

The Transverse Flexure of a Thin Circular Plate Subject to Parabolic Loading Over a Concentric Ellipse. W. A. Bassali. *ZAMP*, May 25, 1960, pp. 176–191. 15 refs. Analysis using the Poisson-Kirchhoff theory and the method of complex potential. Standard formulas for the complex combinations of stress components are used in the computation of the boundary and central values of the bending, twisting moments, and shearing forces. The two limiting cases in which the loaded elliptic path becomes a circle or a line ellipse are also considered.

On the Flexure of Plastic Plates. S. Lerner and W. Prager. *ASME Trans., Ser. E - AM*, June, 1960, pp. 353, 354. Navy-sponsored presentation of a simple test that provides a direct check on the fundamental assumption of the theory of bending of rigid, perfectly plastic plates, when the two bending moments have opposite signs.

Postbuckling Behavior of Rectangular Plates with Small Initial Curvature Loaded in Edge Compression. II. Noboru Yamaki. (*ASME West Coast Conf., Stanford, Sept. 9–11, 1959, Paper 59–APMW-22.*) *ASME Trans., Ser. E - AM*, June, 1960, pp. 335–342. 13 refs. Investigation of the stress in a buckled plate. Numerical results for the square plate are given graphically. The formulas for the ultimate load of the square plate in each case are derived

by using the maximum-shear theory for the beginning of yielding, and comparison is made with the previous results and experiments.

Plates with Holes

Elastic Equilibrium of a Plate with a Reinforced Elliptic Hole. Eugene Levin. (*ASME Annual Meeting, Atlantic City, Nov. 29–Dec. 4, 1959, Paper 59-A-45.*) *ASME Trans., Ser. E - AM*, June, 1960, pp. 283–288. 12 refs. Presentation of an analysis of the problem of an infinite plate with an elliptical hole reinforced by a confocal elliptical ring and subjected to loads in the plane. A solution to the generalized plane-stress problem is obtained using the complex variable techniques of Muskhelishvili. The result is presented in a form well suited to evaluation by digital computers. Specialization to a circular hole with a negligibly thin reinforcement is shown to be in agreement with results obtained previously.

Plastic Stress Concentration at a Circular Hole in an Infinite Sheet Subjected to Equal Biaxial Tension. Bernard Budiansky and O. L. Mangasarian. (*ASME West Coast Conf., Stanford, Sept. 9–11, 1959, Paper 59-APMW-16.*) *ASME Trans., Ser. E - AM*, Mar., 1960, pp. 59–64. Presentation of an analysis determining, for a variety of representative materials, the stress-concentration factor at a circular hole in an infinite sheet of strain-hardening material subjected to equal biaxial tension at infinity. Subsequent calculations reveal that, for a monotonically increasing applied stress, the stress history at all points in the sheet is nearly radial.

Sandwich Construction

Ustoichivost' Trekhsloinykh Pologikh Tsilindricheskikh Panelei s Legkim Zapolnitelem s Zashchemlennymi Prodol'nymi Kromkami pri Osevom Szhatii. V. F. Karavanov. *MVO SSSR VUZ Izv. Av. Tekh.*, No. 2, 1960, pp. 50–60. In Russian. Study of the stability of curved, cylindrical sandwich panels with a light filler, having clamped longitudinal edges in the presence of axial compression.

Testing Methods

Photoelastic Model Engineering. Herbert Becker and George Gerard. (*ASME Semi-Annual Meeting, Dallas, June 5–9, 1960, Paper 60-SA-11.*) *Mech. Eng.*, July, 1960, pp. 43–46. Discussion of the advances in photoelastic stress analysis, including applications to a nuclear-reactor head model and small and large forging press models.

Thermal Stress

Thermal Stresses in Design. XIX—Cyclic Life of Ductile Materials. S. S. Manson. *Mach. Des.*, July 7, 1960, pp. 139–144. 20 refs. Discussion of the design relations – stress-hardening and strain-softening relations, relation of stress range to total strain range, and relations for failure under strain cycling; multiaxiality; design procedure—i.e., determination of strain range and of cyclic life; and quantitative comparisons of the difference in life predictions.

Thermal Stresses in Design. XX—Thermal Cycling with Steady Stress. S. S. Manson. *Mach. Des.*, July 21, 1960, pp. 161–167. Discussion of secondary phenomena which result from an externally applied load, including thermal ratcheting, strain hardening, asymptotic stresses, and practical cases of thermal ratcheting.

Transient Thermal Stresses in a Semi-Infinite Slab. W. Jaunzemis and E. Sternberg. (*ASME Annual Meeting, Atlantic City, Nov. 29–Dec. 4, 1959, Paper 59-A-63.*) *ASME Trans., Ser. E - AM*, Mar., 1960, pp. 93–103. Navy-sponsored investigation of transient temperature and thermal-stress distribution generated in a semi-infinite slab if a finite segment of its edge is subjected to a sudden uniform change in temperature. Exact solutions in series form are obtained both for the heat-conduction problem and for the associated thermoelastic problem. The latter is treated quasi-statically within the classical two-dimensional theory of elasticity. The results corresponding to an instantaneous heating or cooling of a portion of the boundary are used to study the effect upon the stresses of gradual changes in the surface temperature.

Temperature Flexure of Elastic Elements. G. A. Slomyanskii. *U.S., NASA TT F-34*, May, 1960. 20 pp. Translation. OTS, $0.50. Presentation of a method for determining the temperature flexure of an elastic element according to its experimentally determined characteristic curve, taken at a known temperature.

Prediction of Creep Failure Time for Pressure Vessels. F. P. J. Rimrott, E. J. Mills, and Joseph Marin. (*ASME Summer Conf., Univ. Park, Penn., June 20–22, 1960, Paper 60-APM-7.*) *ASME Trans., Ser. E - AM*, June, 1960, pp. 303–308. Analysis of combined stresses in pressure vessels. The creep-failure time is determined for thin, thick, and very thick-walled cylindrical vessels of circular cross section with closed ends subjected to constant internal pressure. A power relation is used to express the creep rate versus stress relation in simple tension.

Wings

Analysis of Low-Aspect-Ratio Aircraft Structures. Ch. H. Samson, Jr., and H. W. Bergmann. (*IAS Natl. Summer Meeting, Los Angeles, June 16–19, 1959, Paper 59-88.*) *J. Aerospace Sci.*, Sept., 1960, pp. 679–693, 711. 27 refs.

An Approximate Analysis of the Influence of Aerodynamic Heating and Initial Twist on the Torsional Stiffness of Thin Wings. L. S. Han. (*ASME Summer Conf., Univ. Park, Penn., June 20–22, 1960, Paper 60-APM-13.*) *ASME Trans., Ser. E - AM*, June, 1960, pp. 332–334. Presentation of approximate formulas, based on the "fiber-stress" concept, for the combined influence of aerodynamic heating and initial twist on the torsional stiffness of a thin wing. Criteria are established for calculating the critical temperature difference between that of the edges and that of the mid-chord position, for preventing possible aeroelastic reversals or buckling. The formulas are valid for wings with large aspect ratios.

Correlation of Theoretical and Photothermoelastic Results on Thermal Stresses in Idealized Wing Structures. Herbert Tramposch and George Gerard. (*ASME Annual Meeting, Atlantic City, Nov. 29–Dec. 4, 1959, Paper 59-A-36.*) *ASME Trans., Ser. E - AM*, Mar., 1960, pp. 79–86. USAF-sponsored investigation comparing the results obtained by the photothermoelastic method with the results of several thermal-stress theories which analyzed the transient thermal stresses in idealized wing structures of high-speed aircraft. It is shown that, owing to simplifying assumptions concerning the thermal behavior in the flanges, thermal stresses predicted by the available theories are all higher than the experimental observation. In some cases, the discrepancy is as great as 30 per cent.

Thermodynamics

Measurement of the Thermal Conductivities of Gases at High Temperatures. R. G. Vines. (*ASME-AIChE Heat Transfer Conf., Storrs, Conn., Aug. 9–12, 1959, Paper 59-HT-2.*) *ASME Trans., Ser. C - HT*, Feb., 1960, pp. 48–52. 16 refs. Navy-sponsored presentation of measurement results for the thermal conductivities of air, argon, nitrogen, and carbon dioxide at temperatures up to 900°C., and of steam up to 560°C. These results are compared with values predicted from correlation formulas based on low temperature measurements.

A Diagram for Thermo Gas-Dynamic Processes. O. Lutz. (*ZFW*, Oct. 1959, pp. 281–286.) *Gt. Brit., RAE Lib. Transl. 889*, Apr., 1960. 13 pp. Presentation of a diagram for thermodynamic processes applicable to air and combustible gases, provided that the dissociation can be neglected.

Combustion

Combustion Experiment with a 53,000-Curie Gold Source. S. W. Churchill, Alexander Weir, Jr., L. F. Ornella, and R. L. Gealer. *U. Mich. Coll. Eng. Dept. Chem. & Metallurgical Eng. TR (AFOSR TR 59-185)*, Nov., 1959. 15 pp.

Amplification of Compression Waves in Interaction with a Flame Front. S. M. Kogarko. (*Zhurnal Tekh. Fiz.*, Jan., 1960, pp. 110–120.) *Sov. Phys. - Tech. Phys.*, July, 1960, pp. 100–108. Translation. Presentation of experimental data obtained in a study of the production and amplification of compression waves in the combustion of air-hydrocarbon mixtures in a spherical chamber, thus offering a qualitative explanation of the effect.

Heat Transfer

Experimental Methods Applied to the Determination of Some Temperature Radiation Parameters. D. T. Kokorev. *Internatl. J. Heat & Mass Transfer*, June, 1960, pp. 23–27. 16 refs. Development of analytical relations that make it possible to establish simple experimental methods of determining angular radiation factors for a general case of a spatial problem. In addition, optical characteristics of a grey surface are found: the average factors of absorption, reflection, and radiation.

Thermal Radiation Between Parallel Plates Separated by an Absorbing-Emitting Nonisothermal Gas. C. M. Usiskin and E. M. Sparrow. *Internatl. J. Heat & Mass Transfer*, June, 1960, pp. 28–36. Presentation of solutions for the governing integral equations over a range of values for the single governing parameter kL (k = the absorption coefficient, and L = the spacing) in the range 0.1 to 2.0. Temperature distribution and heat transfer results are given.

Heat Transfer for Laminar Flow in Ducts with Arbitrary Time Variations in Wall Temperature. Robert Siegel. (*ASME West Coast Conf., Stanford, Sept. 9–11, 1959, Paper 59-APMW-21.*) *ASME Trans., Ser. E - AM*, June, 1960, pp. 241–249. 12 refs. Presentation of an analysis of the laminar forced-convection heat transfer in a circular tube or a parallel plate channel whose walls may undergo arbitrary time variations in temperature. The greater part of the analysis is concerned with the response to a step change in wall temperature, and the time required to reach steady state is given for this type of transient. The results are generalized to apply for arbitrary variations with time.

Heat Transfer Bibliography. E. R. G. Eckert, J. P. Hartnett, and T. F. Irvine, Jr. *Internatl. J. Heat & Mass Transfer*, June, 1960, pp. 102–112. 216 refs. Compilation of 261 references covering the period of 1955 to 1959 and listed in the following groups: applications, books, boundary layer, change of phase, channel flow, conduction, flow with separated regions, low-density heat transfer, natural convection, properties, radiation, transfer mechanisms, and transpiration and mass transfer.

Heat Transfer to Fully Developed Laminar Flow in a Circular Tube with Arbitrary Circumferential Heat Flux. W. C. Reynolds. (*ASME-AIChE Heat Transfer Conf., Storrs, Conn., Aug. 9–12, 1959, Paper 59-HT-13.*) *ASME Trans., Ser. C - HT*, May, 1960, pp. 108–112. Presentation of solutions indicating that the influence of circumferential heat-flux variation on wall temperatures can be quite significant and provide some insight into the nature of the effects. The analysis allows calculation of wall temperatures for any arbitrary peripheral heat-flux variation for fully developed laminar flow under the restriction of constant axial heat input.

Comparison of Turbulent Heat-Transfer Results for Uniform Wall Heat Flux and Uniform Wall Temperature. R. Siegel and E. M. Sparrow. *ASME Trans., Ser. C - HT*, May, 1960, pp. 152, 153. Investigation of the effect of the two wall boundary conditions on the Nusselt numbers for turbulent heat transfer in both the fully developed and thermal entrance regions of a circular tube. It is concluded that for turbulent flow the heat-transfer mechanism in the thermal entrance and fully developed regions is quite insensitive to the two wall boundary conditions examined, at least for the range $Pr \geq 0.7$.

Unsteady Transfer of Momentum and Heat Between Concentric Cylinders. Chia-Shun Yih. (*ASME Hydraulic Conf., Ann Arbor, Apr. 13–15, 1959, Paper 59-Hyd-17.*) *ASME Trans., Ser. D - BE*, Mar., 1960, pp. 210–216. Application of a generalized Fourier analysis to the problem of the molecular transfer of momentum and heat in a fluid between two concentric cylinders, as often encountered in the field of lubrication. In particular, it is shown that varying boundary conditions and nonhomogeneous terms in the diffusion equation which are time-dependent can be treated by the Duhamel method from the theory of the conduction of heat in solids. Heat generated by viscous shear, as well as externally applied, is included in the analysis.

Steady Temperature Field in a Composite Doubly Infinite Strip. Václav Vodička. *Phys. Soc. Japan J.*, July, 1960, pp. 1332–1336. Extension of the classical results on two-dimensional stationary temperature distribution in an infinite plate to the case of a composite strip. General deductions are applied to some special cases leading partly to new results not given in the literature.

The Basic Heat Transfer and Flow Friction Characteristics of Six Compact High-Performance Heat Transfer Surfaces. W. M. Kays. (*ASME Gas Turbine Power Conf., Cincinnati, Mar. 8–11, 1959, Paper 59-GTP-2.*) *ASME Trans., Ser. A - EP*, Jan., 1960, pp. 27–34.

Analytic Formulation for Radiating Fins with Mutual Irradiation. E. R. G. Eckert, T. F. Irvine, Jr., and E. M. Sparrow. *ARS J.*, July, 1960, pp. 644–646. USAF-supported discussion of mathematical formulation for ensembles of radiating-conducting fins. A general configuration is first described and then the governing equations for some specific cases are derived.

Heat Transfer of Combined Free and Forced Convection in Circular and Sector Tubes. L. N. Tao. *Appl. Sci. Res., Sect. A*, No. 5, 1960, pp. 357–368. 17 refs. Analysis in which the coupled momentum and energy equations are combined in the form of a wave equation in the complex domain. Exact solutions are then established in terms of Bessel and associated functions.

A Linear Heat Problem with a Moving Interface. R. E. Gibson. *ZAMP*, May 25, 1960, pp. 198–206. Analysis of the temperature distribution in a body occupying the half-space, $x \geq 0$. The solution of the problem is reduced to

(*Continued on page 111*)

Publications abstracted may be borrowed from the IAS Library. In making inquiry, please mention the month of *Aerospace Engineering* in which the abstract appeared. This will facilitate servicing of requests.

REVIEWS OF *Books*

. . . in the field of aeronautical engineering and space technology

AERODYNAMICS

Theory of Flight. Richard von Mises. (New York, 1945.) New York, Dover Publications, Inc., 1959. 629 pp. $2.85. Reprint.

AERONAUTICS, GENERAL

1959 First Award Papers; IAS Regional Student Conferences. New York, The Minta Martin Aeronautical Student Fund, IAS, 1960. 227 pp.

This is the sixth annual edition of the prize-winning papers of IAS Student Members. These students prepared and presented their papers formally at seven IAS regional conferences held in the spring of 1960. Each paper was judged a first-place winner by a Board of Judges.

Contents: Elementary Analysis of the Turbulent Plate Layer, Abdul Khaliq Azad. On the Minimum Number of Dimensionless Ratios Required to Express the Similarity Parameters of Magneto-Fluid-Dynamics, David L. Clingman. A Theoretical and Experimental Investigation of Drag Reduction by Means of a Shroud About an Axisymmetric Body, Anthony J. Culotta and Thomas P. Kossiaras. Forced Vibration of Aluminum Alloys at Elevated Temperature, Allister F. Fraser. Laminar Boundary Layer Control by Magnetogasdynamic Techniques, Charlie M. Jackson, Jr. A Theoretical Method of Determining the Ground Effect on Lift and Pitching Moment for Wings of Arbitrary Planform, David L. Kohlman. Determining Elastic Deflections due to Bending by the Method of Equivalent Systems, Henry C. Kowalski. Negative Magnus on a Smooth Sphere, Francis J. Lavallee and August Verhoff. The Applicability of Sandwich Construction to Missile Shapes, Joseph S. Pratt. The Stability of Several Missile Nose Configurations in Hypersonic Flow, E. Brian Pritchard. Viscous Effects in Steady, Two-Dimensional, Potential Flow at Supersonic Speed, William J. Rae. A Generalized Solution for Continuous Beams, Donald L. Richardson. Small Aspect Ratio Membrane Flutter, Ronald Stearman. Microwave Interferometer Measurements of Electron Removal in the Argon Afterglow, C. J. Tetrick and R. E. Adler. Some Aspects of Missile Launch Dispersion, John W. Whitehurst. Study of Oscillatory Flame Velocity in Combustion, Carl A. Zierman.

Aerospace Facts and Figures, 1960. Edited by Ben S. Lee. Aerospace Industries Association of America. Washington, American Aviation Publications, Inc., 1960. 148 pp. $2.00.

Statistical information on aircraft production, military aircraft and missile development and procurement, the nation's space program, manpower and finance, helicopters, U.S. airlines, aviation exports, and foreign aviation.

CHEMISTRY

Frozen Free Radicals. G. J. Minkoff. New York, Interscience Publishers, Inc., 1960. 148 pp. $5.00.

The purpose of this monograph is to present the basic features of research into the possibilities of freezing or isolating free radicals, particularly at very low temperatures. The emphasis is on methods favored by a decrease in temperature; fields in which radicals are trapped at room temperature are discussed only briefly.

Dr. Minkoff, who is with the British Petroleum Research Center, assembled his material from research conducted as a Guest Scientist at the National Bureau of Standards in connection with the Free Radical Program sponsored by the U.S. Army.

Contents: 1, Introduction. 2, Early History. 3, Experimental Methods. 4, Basic Principles and Requirements of Trapping. 5, Studies of Individual Atoms. 6, Diatomic and Triatomic Radicals. 7, Polyatomic Radicals Containing C. References. Author Index. Subject Index.

COMPUTERS

Advances in Computers, Vol. 1. Edited by Franz L. Alt. Associate Editors: A. D. Booth and R. E. Meagher. New York, Academic Press, Inc., 1960. 316 pp. $10.

Contents: General-Purpose Programming for Business Applications, Calvin C. Gotlieb. Numerical Weather Prediction, Norman A. Phillips. The Present Status of Automatic Translation of Languages, Yehoshua Bar-Hillel. Programming Computers to Play Games, Arthur L. Samuel. Machine Recognition of Spoken Words, Richard Fatehchand. Binary Arithmetic, George W. Reitwiesner. Author Index. Subject Index.

Digital Computer and Control Engineering. Robert Steven Ledley. Written with the Assistance of Louis S. Rotolo and James Bruce Wilson. New York, McGraw-Hill Book Co., Inc., 1960. 835 pp. $14.50.

This text is directed to senior undergraduate engineering students and first-year graduate students. Prerequisites are college physics, calculus, and at least a first course in electronic circuits.

Part 1 is an introduction to digital programed systems. The treatment leads up to and includes current methods in advanced, automatic programing and concludes with an exposition of the international algebraic language, ALGOL. *Part 2* is concerned with the functional approach to digital-systems design and introduce the Pedagac, a small general-purpose computer designed to illustrate pertinent subject matter from a pedagogical point of view. *Parts 3* and *4* deal with the logical design of digital circuitry and specific computer components based on Boolean algebra and serial arithmetic operations. The last part, *Part 5*, is concerned with the electronic design of digital circuits, including the Pedagac.

The author is Associate Professor of Electrical Engineering, The George Washington University, and Consultant Mathematician, National Bureau of Standards. The coauthors are at the same university.

DICTIONARIES

Air Technical Dictionary, German-English. Edited by H. L. Darcy, in Collaboration with H. Koppe, P. Krekel, F. Lange, K. Leist, P. E. Pank, and A. Spiess. New York, Duell, Sloan & Pearce; Berlin, Walter De Gruyter & Co., 1960. 312 pp. $10.

In this dictionary, experts from various fields of German aviation have compiled those terms considered essential and relevant to each field, and have endeavored to match the German words with corresponding American expressions. Non-essential words, as would be found in general-purpose dictionaries, have been omitted. Air Force slang terms have been included where the terms were considered to be officially acceptable and common to the air technical language. Also, words with a variety of possible usage and application were extracted and translated only insofar as they apply to aeronautical fields. The *United States Air Force Dictionary* was used throughout as the basic authority for spelling and terminology. At least 25,000 terms are given.

ELECTRONICS

1960 Proceedings of the National Aeronautical Electronics Conference, May 2-4, 1960, Dayton. Sponsored by the IRE Dayton Section and Professional Group on Aeronautical and Navigational Electronics; Participation by the IAS. National Aeronautical Electronics Conference, Dayton, Ohio. 508 pp. $5.00.

Contents: 1, Radio Astronomy: The Role of Radio Astronomy in Space Research, A. E. Lilley. Radio Astronomy Receiver Design Techniques, Harold I. Ewen. The World's Biggest Antennas—Radio Telescopes, Carlyle J. Sletten. Radar Approach to Astronomy, P. B. Gallagher and Von R. Eshleman. Solar Radio Astronomy and Some Atmospheric Effects, Robert Fleischer.

2, Solid State Devices: A New Series of High-Power, High-Frequency Silicon Transistors, Frank J. Steinebrey. High Gain Silicon Unipolar Transistors, J. Lawford and C. Y. Chien. Multivibrator Functional Electronic Blocks, H. C. Lin. Gallium Arsenide Tunnel Diodes, N. Holonyak, Jr. A Broad-Area Cadmium Sulfide Photovoltaic Cell, Herbert I. Moss. Can Masers Help "Bridge the Gap"?, Merle N. Hirsh.

3, Energy Conversion Systems: Stumbling Blocks to Power Application, Kelso Jones. Static Power Conversion Equipment, R. P. Putkovich and J. Basista. Thermionic Energy Converters, Walter L. Knecht. Space Nuclear Power Conversion Systems, C. E. Johnson, M. G. Coombs, and R. L. Hirsch. Solar Mechanical Conversion Systems, Donald H. McClelland.

4, Ground Support: Ground Support for Digital Telemetry Systems, C. H. Hoeppner and R. W. Aquais. The Future of Ground Support Equipment in the Space Age, William Schimandle. Support Equipment for Space Probes, Milton C Peterson, Nelson S. Pixley, and John D. Blaisdell. The High Cost of Ground Support Equipment, C. T. Everson.

5, Scientific Education: The National Science Foundation Programs in Education in the Sciences, Harry C. Kelly. Soviet Science and Mathematics Education and Teacher Training, Clarence B. Lindquist. Research and Education for Space Age Technology, Howard K. Nason. The Scientific Teaching of Scientific Material, Felix F. Kopstein. A Design Approach to the Development of a Science Course, J. Jepson Wulff.

6, Molecular Electronics: Molecular Electronics Today—1960, J. A. Hutcheson. Hybrid Engineers and Hybrid Equipment, Daniel E. Noble. Molecular Electronics—Evolution or Revolution?, Julian K. Sprague. Molecular Electronics in Military Equipment, James M. Bridges.

7, Space Reconnaissance Systems: Introduction to Space Reconnaissance Systems, Morley W. Baker, Jr. Optical Recording Equipment—Optical Satellite Detector, L. E. Clements and H. W. Gates. Passive Detection of Ionspheric Objects, Peter Tokareff, Jr. A Super-Fast Recorder for Day and Night Observations of Space Vehicles Using the TV Light Amplifier with Background Compensation, Radames K. H. Gebel.

8, Magnetohydrodynamics: Principles of Magnetohydrodynamic Electric Power Generators, M. E. Talaat. Magnetohydrodynamic Propulsive Devices, W. A. Moser. Plasma Propulsion, Earle B. Mayfield and Richard M. Head. The Plasmajet Rocket Engine, R. J. Page, W. A. Stoner, and P. S. Masser. Optimization of the Efficiency of Energy Transfer to a Condenser for Space Applications, Philip M. Mostov, Joseph L. Neuringer, and Donald S. Rigney.

9, Space Systems Integration: Measuring Systems Integration, Harry G. Romig. On Reliability Prediction in Satellite Systems, George T. Bird. Human Factors Contributions to the Design of a Space Vehicle, Ezra S. Krendel. Optimum Integration of Guidance and Flight Control Systems, R. K. Smyth and E. R. Buxton.

10, Bionics: The Increasing Use of Living Prototypes, Jack E. Steele. Computers and Sensory Neurophysiology, William R. Uttal. Activity in Networks of Neuron-Like Elements, B. G. Farley and W. A. Clark. Considerations in the Design of a Molecular Electronic Analog of the Periphery Auditory Apparatus, L. A. deRosa.

11, Space Communications: Effect of Propagation Fading and Antenna Fluctuations of Communications Systems in the Presence of Jamming, A. B. Glenn and G. Lieberman. Directive Non-Oriented Reflectors as Passive Satellites in Long Distance Communications, Y. E. Stahler and A. L. Johnson. Frequency Allocation for Space Communications Systems, Dr. Jobe Jenkins. Ground-Space Communication System Design, R. T. Smith.

12, Circuits: Two-Phase Servo-Motor Control with Silicon Controlled Rectifiers in a Suppressed-Carrier Modulated System, R. James, H. Moreiness, E. Neumann, H. Wattson. Semiconductor Networks for Audio Frequencies, Arthur D. Evans. Tunnel Diode Circuits and Applications, Clarence J. Carter. Ultralinear Sweep Generators for Use with a Precision Data Storage System, Milton Deever.

13, Interplanetary Environment: A Brief Description of the Natural Environment of Interplanetary Space, John H. Shaw. Estimated Lunar Surface Characteristics for Landing Selection, F. H. Brady and W. G. Green. Some Engineering Aspects of Planetary Atmosphere Entry, F. J. Lyon. Interplanetary Environmental Simulation Problems, K. K. Tempelmeyer.

14, Airborne Computers: A High Speed, General-Purpose Airborne Computer, L. P. Retzinger, Jr. Advanced Space Computers, H. L. Ergott and J. W. Dieffenderfer. Lightweight Navigation Computer for Use with Doppler Navigators, Lewis M. Lawton, Jr. Optimization of Computer Capability Through Programming and Logical Design, Gordon H. Smith.

15, Guidance and Control Systems: Research in Electronic Compensation Methods for Accelerometers of Inertial Navigation Systems, Charles A. Davies. Some Considerations Affecting the Design of Midcourse Navigational Systems for Interplanetary Space Vehicles, Garabed Gulbenkian. A Digital Self-Adaptive Body Bending Filter for Flexible Airframe Control, R. K. Smith, R. M. DuPlessis, L. K. Mattingly. Some Design

Considerations for a Terminal Flare Controller, F. Belsky and J. Doniger.

16, Antennas and Propagation: Design Considerations for Missile and Space Vehicle Antennas, A. F. Gaetano. Multipath in the High Ionosphere, Leonard C. Humphrey and Joseph P. Fragnito. On the Elimination of Communications Dropout during Space Vehicle Reentry, Gail T. Flesher. Instrumentation of a Hypersonic Shock Tunnel for Propagation Measurements, Chester A. Hines.

17, Managing Space Systems: Elements of Typical Space Systems, M. Rosenbaum. Management Problems Peculiar to Space Systems, W. B. Hebenstreit. Programming and Budgeting for Space Systems, George H. Stoner. Management Responsibilities Toward Reliability, R. J. Nordlund. Management—Bridge to the Space Era, Joseph R. Holzapple.

18, Microwave Tubes: A One-Watt C-X Band Traveling-Wave Tube, C. F. R. Lammert and L. J. Zelkowitz. A Feather Weight Travel-Wave Amplifier for Communication Satellites, R. A. Notvest and A. W. Scott. A Satellite Microwave Telemetry Oscillator Using Traveling-Wave Tube Techniques, L. A. Roberts. General Considerations for Cooling High Heat Density Microwave Tubes, David R. Fairbanks and M. Mark.

19, Telemetry: The Case of FM-AM Versus FM-FM Telemetry, L. L. Rauch. A Survey of Some Recent Developments in Reliable FM Communications, Elie J. Baghdady. The Case for Digital Telemetry, F. W. Lehan and R. W. Sanders. A New Radio Interferometer Tracking System, C. H. Grace.

20, Electric Propulsion: XE-700 Series Ion Engine Development, G. Kuskevics and R. N. Edwards. Heavy Ions for Electrical Propulsion, A. L. Cox. On the Flow of Cesium Vapor Through Porous Tungsten, G. M. Nazarian. Dynamical Considerations of a Pulsed Plasma Pinch Engine, I. Garnet, W. J. Guman, and C. C. Cavalconte.

Selected Semiconductor Circuits Handbook. Edited by Seymour Schwartz. New York, John Wiley & Sons, Inc., 1960. 503 pp. $12.

The circuits discussed in this handbook were selected on the basis of inventiveness, reliability, or advanced "state-of-the-art" design. The emphasis throughout is on "building-block" circuitry rather than on systems. The subject matter encompasses direct-coupled amplifiers, low- and high-frequency amplifiers, oscillators, switching circuits, logic circuits, a.c. to d.c. power supplies, power converters, small-signal nonlinear circuits, and magnetic and transistor circuits.

All but two of the ten parts of this book were published by the Navy Bureau of Ships as *Publication NObsr 75231.*

The author is President and Director of Engineering, Transistor Applications, Inc.

GEOPHYSICS

Physics of the Upper Atmosphere. Edited by J. A. Ratcliffe. New York, London, Academic Press, Inc., 1960. 586 pp. $14.50.

This book is concerned with that part of the atmosphere above a height of about 60 km. The physics of the upper atmosphere was being intensively studied during the period (July, 1957, to December, 1958) of the IGY, when the book was being written. A final chapter is therefore included in which the individual authors bring their accounts up to date by inclusion of information available as of December, 1959. The bibliographical notes appended to each chapter are intended to present a full set of references to the most important papers on the subject, complete up to December, 1959. The editor is with the Cavendish Laboratory, University of Cambridge.

Contents: (1) The Thermosphere—The Earth's Outermost Atmosphere, S. Chapman. (2) The Properties and Constitution of the Upper Atmosphere, M. Nicolet. (3) The Upper Atmosphere Studied by Rockets and Satellites, H. E. Newell, Jr. (4) The Sun's Ionizing Radiations, H. Friedman. (5) The Airglow, D. R. Bates. (6) General Character of Auroras, D. R. Bates. (7) The Auroral Spectrum and its Interpretation, D. R. Bates. (8) Radar Studies of the Aurora, H. G. Booker. (9) The Ionosphere, J. A. Ratcliffe and K. Weekes. (10) The Upper Atmosphere and Geomagnetism, E. H. Vestine. (11) The Upper Atmosphere and Meteors, J. S. Greenhow and A. C. B. Lovell. (12) Advances during the IGY 1957/58. Author Index. Subject Index.

Methods and Techniques in Geophysics, Vol. 1. Edited by S. K. Runcorn. London, New York, Interscience Publishers, Inc., 1960. 374 pp. $10.

Contents: Measurement of Temperature Gradient in the Earth, E. C. Bullard. The Measurement of Heat Flow over Land, A. D. Misener and A. E. Beck. Borehole Surveying, T. F. Gaskell and P. Threadgold. Measurement of the Geometric Elements, K. Whitham. Measurements in Palaeomagnetism, D. W. Collinson and K. M. Creer. The Measurement of Gravity at Sea, J. C. Harrison. The Detection of Earth Movements, P. L. Willmore. Earth Currents, G. D. Garland. Properties of Rocks under High Pressure and Temperature, D. S. Hughes. Latitude and Longitude, and the Secular Motion of the Pole, W. Markowitz. Author Index. Subject Index.

MATERIALS

International Symposium on Stress Wave Propagation in Materials. Edited by Norman Davids. Sponsored by Office of Ordnance Research, U.S. Army. Conducted by Dept. of Engineering Mechanics, College of Engineering and Architecture, The Pennsylvania State University, June 30, July 1–2, 1959. New York, Interscience Publishers, Inc., 1960. 337 pp. $10.

Contents: Recent Research in Stress Waves in India, V. R. Thiruvenkatachar. Propagation of an Elastic Strain Pulse in a Semi-Infinite Bar, C. W. Curtis. Propagation of Seismic Pulses in Layered Liquids and Solids, C. L. Pekeris. Viscoelastic Waves, H. Kolsky. Studies in Dynamic Photoelasticity with Special Emphasis on the Stress-Optic Law, M. M. Frocht. Edge Waves in Plates, Sudhir Kumar. Effects of Very Intense Stress Waves in Solids, R. J. Eichelberger. Experimental Studies in Armor Penetration, James R. Kymer. A Review of the Progress in the Measurement of Dynamic Elastic Properties, K. W. Hillier. The Theory of Wave Propagation in Anelastic Materials, E. H. Lee. Some Aspects of the Mechanism of Scabbing, K. B. Broberg. The Role of Stress Waves in the Comminution of Brittle, Rocklike Materials, John S. Rinehart. Some Problems of Transient Analysis of Waves in Plates, Norman Davids. Cinematography of Stress Waves, H. Schardin. Analysis of Dispersed Surface Waves, Yasuo Satô. Author Index. Subject Index.

High Speed Testing, Vol. 1. A Symposium Held at Boston, December 8, 1958. Cochairmen: A. G. H. Dietz and Frederick R. Eirich. Sponsored by Plas-Tech Equipment Corp., New York, Interscience Publishers, Inc., 1960. 112 pp. $5.00.

Contents: Introduction, Frederick R. Eirich. Review of a High-Speed Tensile Testing Program for Thermoplastics, Richard E. Ely. High-Rate Tension Testing of Plastics, Stephen Strella. High-Speed Testing of Composite Solid Rocket Fuels, Harry D. Brettschneider. Impact Testing of Package Cushioning Materials, Richard N. Maxson. Rapid Impact Loading of Textile Yarns, Jack C. Smith. Stress Relaxation—Theory and Practice, Henry M. Morgan. Effect of Strain Rate and Temperature on the True Stress-True Strain Properties of Commercially Pure Titanium, Thomas S. DeSisto and David E. Driscoll. Studies of Metals at Ballistic Rates of Loading, J. O'Brien and R. S. Davis.

MECHANICS

A Treatise on Gyrostatics and Rotational Motion; Theory and Applications. Andrew Gray. (London, 1918.) New York, Dover Publications, Inc., 1959. 530 pp. $2.75. Reprint.

NUCLEAR PROPULSION

Nuclear Flight; The United States Air Force Programs for Atomic Jets, Missiles, and Rockets. Edited by Kenneth F. Gantz. New York, Duell, Sloan and Pearce, 1960. 216 pp. $4.00.

A republication of the Fall–Winter 1959 issue of the *Air University Quarterly Review*, Vol. 11, No. 3–4. The editor is a Lieutenant Colonel in the USAF.

Contents: Editor's Introduction, K. F. Gantz. Air Force Nuclear Propulsion: Nuclear Propulsion and Aerospace Power, T. D. White.

(1) The Prospect for Nuclear-Powered Flight: The Payoff in Nuclear Propulsion, R. C. Wilson. The USAF Nuclear Propulsion Programs, D. J. Keirn. Manned Aircraft Nuclear Propulsion Program, W. A. Tesch. Nuclear Missile, Rocket, and Auxiliary Power Programs, J. L. Armstrong.

(2) Principles of Nuclear Propulsion: Power-Reactor Fundamentals, T. L. Jackson. Thrust and Power Production from Nuclear Energy, J. P. Wittry. Heat Transfer and Coolant Systems, J. P. Wittry. Reactor Materials, J. J. Connelly, Jr. The Shield, F. R. Westfall.

(3) Status of Program: Direct-Cycle Nuclear Propulsion, D. R. Shoults. Indirect-Cycle Nuclear Propulsion, K. K. Klingensmith and C. D. Lingenfelter. Nuclear Reactors for Ramjet Propulsion, T. C. Merkle. Design of a Nuclear Ramjet, A. R. Gruber. Nuclear-Rocket Propulsion, R. E. Schreiber. Radioisotopic Power Sources, J. G. Morse. Nuclear Reactors as Auxiliary Power Sources, J. G. Wetch. Testing Radiation Effects on Aircraft Systems—The USAF Support Program, W. C. Shiel.

(4) The Human Element: Radiobiological Aspects of Aircraft Nuclear Propulsion, J. E. Pickering and G. L. Hekhuis. Human Factors of Nuclear-Powered Aircraft, C. A. Dempsey. Ground Support for Nuclear Aircraft, H. S. Hutchins. Public Hazards from Nuclear Aircraft, B. P. Leonard, Jr. and F. G. Gillesby.

Appendix: Glossary of Terms, R. C. Hoewing. Index.

SPACE TRAVEL

Introduction to Space. Lee A. DuBridge. New York, Columbia University Press, 1960. 93 pp. $2.50.

This work consists of four George B. Pegram Lectures delivered by the President of the California Institute of Technology to an audience of laymen and scientists at Brookhaven National Laboratory.

Contents: Attaining a Space Orbit. The Space Laboratory. The Solar System. The Universe.

Strange World of the Moon; An Inquiry into its Physical Features and the Possibility of Life. V. A. Firsoff. New York, Basic Books, Inc., 1959. 226 pp. $6.00.

The author, a Fellow of the Royal Astronomical Society, has intended this work for the general reader. However, the bibliographic citations in the text, the references collected at the end of each chapter, the mathematical and technical appendixes, and the detailed subject and author indexes are characteristic of a specialized reference work.

STRUCTURES

Theory of Thermal Stresses. Bruno A. Boley and Jerome H. Weiner. New York, John Wiley & Sons, Inc., 1960. 586 pp. $15.50.

This book is divided into four parts, of which the first and last are concerned with the more theoretical aspects of the subject matter under discussion and the second and third with a more practical approach to the determination of stresses produced in a solid object under specified heating conditions. *Parts 2* and *3* are largely self-contained and require a less extensive theoretical background than *Parts 1* and *4;* thus the book is aimed at both the researcher and the practicing engineer, as well as at the student.

In *Part 1* the fundamentals of thermoelasticity are developed, from mechanical and thermodynamical foundations and up to alternate formulations and methods of solutions of thermoelastic problems. *Part 2* recounts heat-transfer theory and the methods of solution of heat-conduction boundary-value problems. More practical aspects of thermal stress analysis, mainly from the strength-of-materials point of view, are presented in *Part 3.* In *Part 4* the manner in which temperature effects can be included in inelastic theory is given, together with problems involving viscoelastic idealization and plastic flow.

Dr. Boley is Professor of Civil Engineering, Institute of Flight Structures, Columbia University, where Dr. Weiner is Associate Professor of Mechanical Engineering.

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Reviews

(Continued from page 109)

that of a singular Fredholm equation of the first kind.

VTOL & STOL

More V/STOL Funding, Firmer Specs Needed Now for Operational Status. E. R. Heald and R. A. Young. *Western Av.*, July, 1960, pp. 22, 23. Summary of the studies on the technical and economic feasibilities of VTOL and STOL aircraft, performed by the Douglas Aircraft Company.

What's Needed for Automatic VTOL Landings? C. Snowdon. *Space/Aeronautics*, July, 1960, pp. 58–60. Presentation of the requirements of an automatic landing system. It is noted that VTOL's are better suited to blind landings than conventional planes.

Jet Lift for Supersonics. David Keith-Lucas. *Shorts Quart. Rev.*, May, 1960, pp. 2–4. Discussion of the need for a VTOL aircraft for military use and of Griffith's ideas of a jet lift, narrow delta, supersonic airliner, which had a special significance in the design of Short SC.1.

Shorter and Shorter. *Aircraft*(Canada), June, 1960, pp. 10, 11. Description of the features incorporated in the Otter aircraft during the joint DRB-DHC STOL research program which has been under way at de Havilland Canada's Downsview facility.

Etude en Courant Plan d'une Plateforme à Effet de Sol. Ph. Poisson-Quinton. (*Symposium on Ground Effect Phenomena, Princeton, Oct. 21, 1959.*) *France, ONERA NT 57*, 1960. 26 pp. 12 refs. In French. Investigation of the principles of ground effect machines limited to the case of two-dimensional flow. Includes description of flow visualization measurements made in a hydrodynamic tunnel, results on the aerodynamic characteristics of the platform, as well as details of the experimental setup and methods used. Appended are the results of two preliminary studies on the use of annular jets.

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982. Aeronautical Engineer—B.Aero.E., age 27. Five years' experience in the aircraft industry—2 years supervising wind testing of VTOL vehicles, 3 years in theoretical aerodynamics and aircraft design. Demonstrated ability in achieving working integration of aerodynamic, mechanical, and electrical concepts. Looking for a responsible position with growth potential in an expanding organization. East Coast preferred. Complete résumé on request.

981. Project Engineer—age 39. M.S.Ae. Eighteen years' experience in the aircraft industry—structures, preliminary design, project engineering, and project management. Top-notch technical and administrative talents. Desires growth situation with advanced aerospace vehicle or component manufacturer.

978. Staff/Project Engineer—age 38. B.S. Ae.E.; B.S.M.E.; Professional Engineer—M.E. (Michigan). Lt. Comdr., USNR-R, 12 years. Diversified experience in responsible project supervision and operational engineering in design, research, and development in aircraft and automotive gas turbine, and rocket engine propulsion devices, with outstanding background in the research areas of prototype components manufacture. Experienced in all fabrication techniques, budgets, cost estimating, proposals, client and supplier contact, and supervisory and administrative functions. Desires responsible position with progressive company.

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